ARMY RESEARCH LABORATORY

Cognitive and Physiological Performance of Soldiers While They Carry Loads Over Various Terrains

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Abstract

This study examined the cognitive and physiological performance of soldiers as they carried loads over various terrains. Twelve soldiers each carried a light load (total weight, including clothing, 22.77 kg [50.19 lb]) and a heavy load (total weight, including clothing, 36.94 kg [81.43 lb]) over three terrains: blacktop road, sand, and mud. The cognitive tasks performed by the soldiers included arithmetical, memory, and monitoring tasks. The physiological variables were oxygen uptake, ventilation rate, heart rate, and rating of perceived exertion. Test participants also rated their overall workload after each trial. The results showed a significant ($p = .018$) Load x Block interaction for the monitoring task. In Block 2 (i.e., the second time period during which the monitoring task was performed), the error rate for the light load condition was significantly lower than the error rate for the heavy load condition. There were significant main effects of load, terrain, and time for all the physiological variables. In this study, the energy expenditure (oxygen uptake) for walking on mud or loose sand was the same, and it was approximately 40% higher than the energy expenditure for walking on the blacktop road. Subjective ratings of workload showed significant differences as a function of load ($p = .006$) but not terrain.

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CONTENTS

EXECUTIVE SUMMARY

Cognitive performance and physiological performance have been examined separately in much of the previous research. However, emerging soldier systems such as Land Warrior concurrently require high cognitive and physiological workload. Therefore, the goal of this study was to examine both the cognitive and physiological performance of soldiers as they traversed various terrains while carrying two different loads.

There were three objectives in this study:

1. To determine the effects of carrying loads over various terrains on the cognitive performance of the test participants.

2. To examine the physiological performance of the test participants as they carried loads over various terrains, particularly slippery terrain because it has not been studied.

3. To collect data that can be used to enhance existing software tools used to model cognitive and physiological performance.

This study used a within-subjects design. The independent variables were load, terrain, and time or block.[1] The dependent variables were percent error on the cognitive tasks, oxygen uptake (VO_2), ventilation rate (VE), heart rate (HR), rating of perceived exertion (RPE), and responses to a questionnaire regarding workload. There were two loads: the fighting load with individual clothing (22.77 kg [50.19 lb]) and the existence load with individual clothing (36.94 kg [81.43 lb]). There were three terrains: blacktop road, loose sand, and a muddy field with plywood lying in the path. There were three cognitive tasks: arithmetic, memory, and monitoring. Test participants were paced at 1.1 m/s (2.5 mph) as they carried the load over the test courses. The distance they covered in each 1-hour data collection trial was 4.0 km (2.5 mi.).

During each data collection trial, test participants answered only arithmetical questions from the 10th to the 15th minute. They responded to all three cognitive tasks from the 20th to the 35th minute and again from the 40th to the 55th minute. Physiological data were collected during three 5-minute periods from the 15th to 20th, 35th to 40th, and 55th to 60th minutes. At the end of each data collection trial, participants were given a questionnaire to assess their overall workload during the trial.

Twelve male soldiers from Aberdeen Test Center's (ATC) Military Support Company participated in this study. The study was fully explained to the participants, and each participant

[1]Block is the time period during which the cognitive tasks were performed.

read and signed a volunteer consent form. The soldiers who participated in this study were representative of the anthropometric and physical fitness characteristics of soldiers in the U.S. Army. All the test participants had previous experience carrying loads equivalent to the ones carried in this study, and they were fully acclimated to Aberdeen Proving Ground (APG), Maryland.

The data collection trials took place 26 May through 4 June 1998 at APG. The trials were conducted during daylight between 9:00 and 16:30 eastern daylight savings time except for one trial that began at 7:50 and two trials that ended at 16:45 and 17:20. The participants were divided into three groups of four soldiers. Test participants completed two trials each day their group participated. Water was available for the test participants to drink during the trials. Between trials, participants had time to rest, drink water, and eat. The data collection days alternated so that each group had at least one day of rest between data collection days.

Separate analyses of variance (ANOVAs) were conducted for each evaluation (cognitive and physiological). A repeated measures ANOVA was conducted on the dependent variables (percent error on the cognitive tests, overall workload based upon the questionnaire, VO_2, VE, HR, and RPE) using the independent variables (load, terrain, and time or block). These analyses included a check for compound symmetry. If the assumption for compound symmetry was violated, then the conservative Greenhouse-Geisser correction for the degrees of freedom was used. The level of significance for these analyses was 0.05. Tukey's Honestly Significant Difference (HSD) Test was used to determine significant differences among the means.

The overall mean error for the auditory monitoring task was 1.7%. The ANOVA on the auditory monitoring task data showed a Load x Block (time) interaction. Tukey's HSD Test was performed on these data. The results indicate that in Block 2 (i.e., the second time period during which the monitoring task was performed), the light load condition had a significantly lower error rate than did the heavy load condition. The light load condition in Block 2 also had a significantly lower error rate than did either load condition in Block 1.

Carrying the light load showed an increase in performance of the monitoring task over time. The increase in performance of the monitoring task is evidence of a beneficial relationship between exercise and cognitive performance. Carrying the light load may cause an exercise-induced increase in alertness, which results in improved performance of the monitoring task.

The overall mean error for the arithmetical and memory tasks was 13.5% and 8.2%, respectively. However, no significant differences were shown for the arithmetical and memory tasks. In this study, exercise had no effect on performance of these tasks. This may be because of

the structured presentation of the questions, the method of presentation (one cognitive task at a time), the fact that the soldiers were well trained before the data collection trials began, or the physical exertion may not have been intense enough to affect performance of these tasks.

After each data collection trial, a questionnaire was administered to assess overall workload. Overall workload is based upon the subject's assessment of physical demand, mental demand, temporal demand, performance, effort, and frustration. The results of the ANOVA on the data from the questionnaire showed a main effect of load but not terrain. Test participants perceived that carrying the heavy load on any terrain while answering the cognitive questions caused a greater overall workload.

The results of the ANOVA on the physiological data showed significant main effects of terrain, load, and time for all the variables (VO_2, VE, HR, and RPE). There were also Load x Time or Terrain x Time interactions for all these variables. Overall, the results of this study are consistent with normal physiological responses to walking while carrying loads.

Blacktop road was the baseline condition for this study. Energy expenditure, as measured by oxygen uptake, was lowest on blacktop road. Energy expenditure was approximately 40% higher on loose sand and mud. With regard to slippery terrain, it is interesting to note that there was no statistically significant difference between the energy expenditure for the mud and loose sand conditions.

Although it is beyond the scope of this report, there are two ways that the data collected in this study can be used to enhance existing software tools used to model soldier-system performance. First, data from this study can be used to validate output from the models. Second, algorithms that describe a soldier's performance of these tasks could be developed and incorporated into the models after appropriate verification and validation.

To gain a thorough understanding of the combined cognitive and physiological performance of soldiers carrying loads over various terrains, more research needs to be done. This additional research needs to answer the following questions: (a) What is the optimum load for achieving maximum performance of monitoring tasks? (b) If the march continues for several hours, how is performance of the monitoring task affected? (c) How would combinations of other cognitive measures (decision-making tasks and multiple tasks that must be done simultaneously) and a more strenuous physical component (a variety of speeds, grades, and unpredictable terrain) affect performance?

COGNITIVE AND PHYSIOLOGICAL PERFORMANCE OF SOLDIERS WHILE THEY CARRY LOADS OVER VARIOUS TERRAINS

INTRODUCTION

Purpose

Most of the past research efforts regarding cognitive and physiological performance have focused on quantifying these two types of performance separately. The aim of this study is to examine both the cognitive and the physiological performance of soldiers as they traverse various terrains. This is an area of research that has important implications for equipment being developed for dismounted soldiers. As new technologies are introduced into the military, soldiers are expected to use them to perform their missions better. Many of these new technologies require a soldier's cognitive resources. If there are significant differences in a soldier's cognitive performance while he or she carries loads over various terrains, this information will be important in determining the appropriate use of technologies that require a soldier's cognitive abilities. For example, new communications and situational awareness systems are being developed for the "digitized battlefield." If soldiers are traversing difficult terrain, will they be able to act upon information from those new systems effectively?

The Effects of Energy Expenditure on Cognitive Ability

The effects of exercise on the human body have been well documented in the literature. Most of this research has focused on the physiological changes that occur in the body in response to exercise or physical exertion (i.e., cardiovascular, respiratory, muscular, skeletal, etc.). However, there has been little research about the relationship of physical exercise to mental performance. Research, which has specifically focused on the effects of exercise on mental performance, has provided conflicting findings (Tomporowski & Ellis, 1986).

Studies Finding a Beneficial Relationship

A few studies have found a beneficial relationship between exercise and mental performance. Burgess and Hokanson (1964) found that performance of a digit-symbol substitution in an equal number of male and female subjects improved after mild exercise. McGlynn, Laughlin, and Bender (1977) found that running on a treadmill at increasing speeds and gradients significantly improved the speed of male college students in performing a discrimination task, without impairing their accuracy. Hogervorst, Riedel, Jeukendrup, and Jolles (1996) evaluated performance of

psychomotor and cognitive tasks administered before and immediately after exercise on a cycle ergometer. Results indicated improved performance of the cognitive tasks after exercise. Lybrand, Andrews, and Ross (1954) assessed the effects of aerobic activity on cognitive processes. This research measured the effects of a 5-mile march with a 40-pound pack on the perceptual ability of college students. They found the scores on tasks such as Perception of Hidden Figures and Kobs Block Designs were higher after mild physical activity than during periods of no exercise and sleep deprivation. In a similar study, Gliner, Matsen-Twisdale, Horvath, and Maron (1979) observed that the aerobic energy production of a marathon race facilitated the performance of adult men in a vigilance signal-detection task. Subjects consistently made fewer false-positive responses to the detection task for several hours after the completion of the race, suggesting that the subjects' sensitivity increased as a result of the endurance exercise.

Studies Finding a Detrimental Relationship

There have also been studies that suggest a detrimental influence of exercise on cognition. Hancock and McNaughton (1986) investigated the effect of physical exertion to the point of fatigue on two visual perception tasks. Subjects were experienced orienteers. One test was conducted while the subjects were in a rested state, and the other test was conducted while they were in a state of fatigue (working at or above their anaerobic threshold determined by VO_{2max} test). Data suggest that under the influence of fatigue, an orienteer's ability to perceive visual information is greatly impaired. Fleury and Bard (1987) found that sensory and adaptive behaviors improve with previous physical activity, but cognitive performance is impaired by highly demanding (maximal aerobic) efforts. Weingarten (1973) found a decrement in cognitive task performance during physical exercise. This research suggests that the initial level of physical fitness of subjects will interact with task performance. Subjects with low cardiorespiratory fitness showed marked decrements in task performance, and those with high fitness were able to maintain their performance after strenuous exercise.

Studies Finding Both a Beneficial and a Detrimental Relationship

Davey (1973) found an inverted "U" relationship between physical exertion and attention of male and female teachers. As metabolic activity increased, performance also increased up to a point; with further metabolic activity, performance decreased. Gupta, Sharma, and Jaspal (1974) investigated the influence of physical activity on the efficiency of mental work. Subjects were given charts that contained sets of one-digit numerals and performed a series of addition, subtraction, multiplication, and division with the numerals in a random order. Results indicated a significant

increase in mental work performance when the physical activity was of 2 to 5 minutes' duration and a significant decrease in performance when the physical activity was 10 and 15 minutes.

Studies Finding No Relationship

In a test of the effect of physical exercise on verbal, visio-spatial, and numerical performance, Zervas (1990) concluded that intensive physical exercise does not impair mental performance. Tomporowski, Ellis, and Stephens (1985) investigated the effects of running on a treadmill to exhaustion on free recall memory. The results show no differences between the number of words recalled following strenuous exercise and the number of words recalled by the non-exercise control group. Sparrow and Wright (1993) found that short duration (6 minutes) aerobic exercise has no effect on cognitive performance.

Issues That Must be Addressed

Although the previously cited studies provide some information about the effects of physical exertion on mental performance, a number of questions remain unanswered. These questions are important, especially for the dismounted soldier who must constantly adapt to the changing battlefield environment and must successfully complete tasks necessary for each mission. The results of the studies reviewed do not provide a clear indication of whether exercise influences cognition, and if it does, whether the influence is beneficial or detrimental. In light of this, Tomporowski (1986) lists several points that must be considered when the influence of exercise on cognitive performance is examined:

1. The effects of an exercise intervention will depend on the fitness level of the subject being tested.

2. The effects of exercise will differ, depending on the intensity and duration of the exercise and whether cognitive tasks are administered during or after exercise.

3. Cognitive tasks differ in their ability to isolate different types of mental processes.

Energy Expenditure Studies of Military Tasks

Since the 1920s, studies have been conducted to measure the energy expenditure of soldiers performing various tasks. In their report, Passmore and Durnin (1955) summarized early studies of physiological performance during military tasks. They presented the results of studies done

with British, Yugoslavian, and American soldiers. The soldiers were engaged in a variety of activities from dressing and undressing (2.5 kcal/min) to running an obstacle course (6.2 kcal/min), digging trenches (8.8 kcal/min), and field marching with heavy packs (8.9 kcal/min). In an examination of load carrying by infantry soldiers, Gupta (1955) measured oxygen consumption for soldiers marching with various loads. Using the oxygen consumption data to calculate energy expenditure shows that energy expenditure ranged from 1.4 kcal/min for marching without a load to 5.4 kcal/min for marching with 28.6 kg (63 lb). Malhotra, Ramaswamy, and Ray (1962) examined energy expenditure for Indian soldiers performing a variety of tasks. There are differences between these results and the results reported by Passmore and Durnin for British and American soldiers. For example, Malhotra, Ramaswamy, and Ray found the energy expenditure for trench digging to be only 7.2 kcal/min versus 8.8 kcal/min for British soldiers in India. Malhotra, Ramaswamy, and Ray attribute these differences to the ways the activities were performed rather than to racial differences. Goldman (1965) conducted a study of the energy expended by soldiers who were wearing chemical protective equipment while they were engaged in simulated combat missions in a tropical jungle. Energy costs ranged from 2.5 kcal/min for a rifleman resting to 8.0 kcal/min for an M-60 machine gunner in a jungle fire fight.

Studies to Predict Energy Expenditure When People Carry Loads

Equations to predict energy cost have been developed by Ralston (1958); Cotes and Meade (1960); Bobbert (1960); Grimby and Soderholm (1962); Workman and Armstrong (1963); Givoni and Goldman (1971); van der Walt and Wyndham (1973); Pandolf, Givoni, and Goldman (1977); Zarrugh and Radcliffe (1978); and Epstein, Stroschein, and Pandolf (1987). These equations predict energy cost for walking and running when various loads are carried. In addition, Soule and Goldman (1972) and Pandolf, Haisman, and Goldman (1976) examined the effects of terrain on energy expenditure. In general, energy expenditure increases as a function of increasing load, speed, or grade. The type of surface also affects energy expenditure. For example, loose sand and soft snow require greater energy expenditure than does blacktop road. Also, Epstein, Rosenblum, Burstein, and Sawka (1988) and Patton, Kaszuba, Mello, and Reynolds (1991) found that energy cost during prolonged load carriage increases over time.

Slippery Surfaces

For soldiers carrying external loads, not only are the weight of the load and the time for which it must be carried important, but also the terrain over which it must be carried. Although Soule and Goldman (1972) and Pandolf, Haisman, and Goldman (1976) examined many terrains when they

developed their terrain coefficients, they did not examine slippery surfaces. Some of the slippery surfaces soldiers might encounter include roads or trails covered with ice, wet leaves, or mud.

Miller (1983) suggested that the minimum static coefficient of friction (COF) should be 0.5 when people walk unloaded on a level surface. Thus, when the static COF is less than 0.5, the walking surface-contaminant-shoe sole combination is likely to be considered slippery. A study by Swensen, Purswell, Schlegel, and Stanevich (1992) found that subjects could identify differences in slipperiness as measured by the static COF. One of the conditions in their study was for subjects to walk across steel beams with wet clay on their boot soles. The subjects rated this condition slippery when the static COF was in the range of 0.39 to 0.42.

OBJECTIVES

This study has three objectives:

1. To determine the effects of carrying loads over various terrains on the cognitive performance of the test participants.

2. To examine the physiological performance of the test participants as they carried loads over various terrains, particularly slippery terrain because it has not been studied.

3. To collect data that can be used to enhance existing software tools used to model cognitive and physiological performance of soldiers.

The null hypotheses of this study are stated as follows:

1. There will be no difference in cognitive performance as a function of load carried.
2. There will be no difference in cognitive performance as a function of terrain traversed.
3. There will be no difference in physiological performance as a function of load carried.
4. There will be no difference in physiological performance as a function of terrain traversed.

METHODOLOGY

Experimental Design

The goal of this study was to examine the cognitive and physiological performance of soldiers carrying loads over various terrains. The independent variables were load, terrain, and time

or block. There were two loads: the fighting load with individual clothing and the existence load with the individual clothing. The total weight for the fighting load with the individual clothing was 22.77 kg (50.19 lb). The total weight for the existence load with the individual clothing was 36.94 kg (81.43 lb). There were three terrain conditions: blacktop road, loose sand, and a muddy field with sheets of plywood lying in the path. Blacktop road was the baseline condition. Loose sand was a condition that required a high energy expenditure. The muddy field with sheets of plywood spaced for participants to walk over was the slippery condition. There were three cognitive tasks: an arithmetical task, a memory task, and a monitoring task. The dependent variables were percent error on the cognitive tests, oxygen uptake (VO_2), ventilation rate (VE), heart rate (HR), rating of perceived exertion (RPE), and responses to a questionnaire regarding workload.

Every test participant carried each load over each test course. Each soldier completed two data collection trials per day. Both data collection trials were completed on the same terrain. In one trial, the participant carried the fighting load; in the other trial, the participant carried the existence load. Each data collection trial was 1 hour long. There were six load-terrain combinations. Therefore, test participants completed six 1-hour data collection trials.

Participants

Twelve male soldiers from Aberdeen Test Center's (ATC) Military Support Company participated in this study. (Figure 1 shows a soldier with the equipment used in this study.) The study was fully explained to the participants, and each participant read and signed a volunteer consent form. Then, each participant completed a survey about his current medical status and fitness to take part in the study.

After the consent form was completed, the principal investigator reviewed the medical status survey. No one who was on medical profile for an injury, illness, or other condition that could affect his ability to carry a load or who had a health-related concern about his safe participation in this study was allowed to participate.

The soldiers who participated in this study were representative of the anthropometric and physical fitness characteristics of soldiers in the U.S. Army. Table 1 gives the mean and standard deviation (SD) age, stature, and weight of the participants. Table 1 also shows the age, stature, and weight of the soldiers in the 1988 anthropometric survey of U.S. Army personnel (Gordon et al., 1989). All the soldiers in ATC's Military Support Company participate in a regular physical training program. The program consists of strength training and aerobic exercise (i.e., running 2 to 5 miles three or four times per week). Two-mile run time is highly correlated with maximum oxygen

uptake (VO_{2max}), which is the laboratory measure of aerobic fitness (Mello, Murphy, & Vogel, 1988; Knapik, 1989). Test participants completed a 2-mile run as part of their Army Physical Fitness Test (APFT) 2 weeks before this study. The mean 2-mile run time was 14.21 minutes (0.76 SD). This time is typical of the average soldier in today's Army (Fitzgerald et al., 1986; Knapik et al., 1994). In the time between the 2-mile run and this study, the test participants' physical training program did not change, and they were fully acclimated to the climate at Aberdeen Proving Ground (APG). Another measure of physical fitness is percent body fat. The mean body fat for the test participants was 17.6% (5.0 SD). For soldiers in the age range 22 to 35, this is the expected percent body fat (Vogel, Kirkpatrick, Fitzgerald, Hodgdon, & Harman, 1988).

Figure 1. Test participant with all equipment.

Table 1

Age, Stature, and Weight of Test Participants (n=12) and 1988 Anthropometric Survey Sample (n=1774) Mean (SD)

	Age (years)	Stature (cm)	Weight (kg)
Present study	26.0 (3.9)	180.1 (4.9)	81.7 (10.1)
1988 anthropometric survey	27.2 (6.8)	175.6 (6.7)	78.5 (11.1)

To assess the load-carrying experience of the test participants, the questionnaire in Appendix A was administered. All the test participants had previous experience carrying the equipment used in this study. They had also carried loads equivalent to those carried in this study. All but three of the 12 test participants had carried a load for 1 hour or more during the past year.

Apparatus

The following equipment was used during this study:

Individual Clothing—Table 2 shows the items of individual clothing and their weights. These items are the clothing specified in MIL-STD-1472D (Department of Defense, 1989). The only difference is that the personal armored system for ground troops (PASGT) vest was eliminated. Participants wore their own battle dress uniforms (BDU) and their own boots.

Table 2

Individual Clothing

	Weight	
Item	Kilograms	Pounds
Helmet	1.36	3.00
Battle dress uniform (BDU)	1.73	3.81
Underwear, socks, belt	0.36	0.80
Boots	1.52	3.36
TOTAL	4.97	10.97

Fighting Load—Some of the fighting equipment specified in MIL-STD-1472D was used in this study. The rest of the equipment was simulated by placing an equivalent weight in an all-purpose individual carrying equipment (ALICE) pack. The distribution of weight within each pack was the same. Table 3 gives the items that comprise the fighting load and their weights.

Table 3

Fighting Load

Item	Weight Kilograms	Weight Pounds
Mock M16A1 rifle (weighted to simulate an M16A2)	3.72	8.2
Load-carrying equipment (LCE) with mock ammunition, two inert grenades, and two canteens of water	7.27	16.0
ALICE pack with Oxylog2® and cognitive measures recording system weighted to simulate other equipment	6.81	15.02
TOTAL	17.80	39.22

Existence Load—The weight of the existence load as specified in MIL-STD-1472D is 14.17 kg (31.24 lb). In military training or operations, if a soldier is carrying the existence load, he or she also carries the fighting load. Therefore, in this study, the weight in the ALICE pack for the fighting load was placed in an ALICE pack for the existence load. The distribution of weight within each pack was the same. Table 4 shows the weight of the existence load carried in this study.

Table 4

Existence Load

Item	Weight Kilograms	Weight Pounds
Mock M16A1 rifle (weighted to simulate an M16A2)	3.72	8.2
LCE with mock ammunition, two inert grenades, and two canteens of water	7.27	16.0
ALICE pack weighted to simulate existence load plus 6.81 kg (15.02 lb) from fighting load	20.98	46.26
TOTAL	31.97	70.46

Oxylog2® with a Series 2700, large, two-way, non-rebreathing valve (Hans Rudolf, Inc., Kansas City, MO)—This device is used to determine energy expenditure. Test participants breathe into a mouthpiece attached to the two-way, non-rebreathing valve that is connected to the measuring unit via respiratory tubing. This device measures the volume and oxygen content of expired air. It then calculates oxygen uptake (the volume of oxygen used per minute [VO_2]) and ventilation volume (the amount of air exhaled per minute [VE]).

Polar® Heart Watch—This device measures heart rate (HR). It consists of a strap that goes around the test participant's chest and a watch that can be worn on the wrist or attached to the ALICE pack. The chest strap contains a sensor that detects electrical impulses from the heart and a transmitter that sends them to the watch. The watch displays the HR in real time and updates the average HR every 5 seconds (see Figure 2).

Figure 2. The Oxylog2®, its display unit, and the heart watch.

Anthropometer—An anthropometer (manufactured by GPM, Switzerland) was used to measure the participants' stature.

Electronic Scale—An electronic scale (Model 770 manufactured by Seca Alpha, Germany) was used to measure the participants' weight.

Pacing Wheel—This device was used by one of the investigators who walked in front of the test participants to set the speed for each trial. It consists of a bicycle speedometer attached to the front wheel and front fork of a bicycle. The front wheel and fork have been removed from the rest of the bicycle. A handle is attached to the fork for ease of use. The pacing wheel was calibrated on a treadmill for walking and running speeds.

Gulick Measuring Tape—This measuring tape is used in anthropometry to measure circumferences. The circumference measurements are used to estimate body composition.

Borg Scale—This is used to measure rating of perceived exertion (RPE) (Borg, 1973). It is a 15-point psychophysical scale ranging from 6 to 20. The odd numbers are anchored with verbal descriptions from "very, very light" to "very, very hard." The scale is printed on a piece of paper, and test participants assess their own physical exertion by choosing a number from the scale.

Cognitive Measures Recording System—This system, shown in Figure 3, consists of a tape player with earphones, a clip-on microphone, and a tape recorder. The tape player plays an audio cassette tape of the cognitive questions. Test participants hear the questions through the earphones. At the same time, each question is recorded on the tape recorder. Then the microphone detects the participant's answers, which are recorded by the tape recorder.

Friction-Measuring Device—This device is shown in Figure 4. It consists of a baseplate, winch, digital scale, two pulleys, and a cable that runs from the winch around a pulley attached to the digital scale and out to a pair of boots attached to a wood framework. The boots are Government issue size 11R speed lace boots filled with concrete so that they maintain their shape. The total weight of the boots, the framework, and a steel weight on top of the framework is 14 kg (31 lb).

Soil Penetrometer—This is a standard device for determining trafficability of various soils. It is most often used to determine trafficability for military vehicles. The penetrometer is pushed into the ground and readings are taken at various locations. A 0- to 300-lb soil penetrometer (Federal stock number [FSN] 6635-697-5761) was used in this study on the sand and mud courses.

Soil Density and Moisture Content Measuring Device—The Model C-200 nuclear density-moisture meter from Seaman Nuclear (Oak Creek, Wisconsin) was used to measure the density and moisture content of the soil on the sand and mud courses. This device, which contains a radio-active source, uses the air-gap backscatter method to measure density and moisture content.

Figure 3. The cognitive measures recording system in an ALICE pack.

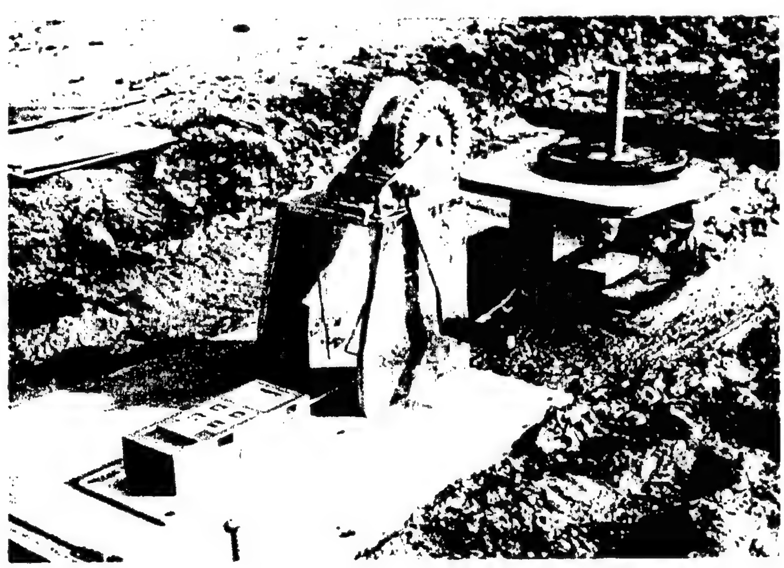

Figure 4. The friction-measuring device.

Blacktop Road—On the Munson Test Course at APG, a level section of blacktop approximately 100 m long by 6 m wide (328 ft long by 20 ft wide) was used for the baseline condition. Test participants walked around a loop on this section of blacktop road. During testing, this section of roadway was blocked so that there would be no vehicular traffic. The static COF of the blacktop road is given in Appendix B.

Sand Course—The volleyball courts at an area of APG known as the Marylander Club were used for the sand course. The surface of the volleyball courts is beach sand approximately 15.24 cm (6 in) deep. Test participants walked along an oval path approximately 18.3 m (60 ft) long and 9.1 m (30 ft) wide on the volleyball courts. The soil penetration, moisture content, and density of the sand course are shown in Appendix B.

Mud Course—The mud course was created in an open field, known as the dig site, at the Perryman Test Course on APG. ATC personnel leveled a 100-m by 6-m (328-ft by 20-ft) area. Sheets of plywood were laid in the level area, and the course was sprayed with water to create mud. The sheets of plywood were spaced several feet apart so that test participants walked from mud to plywood and back to mud as they traveled the course. Plywood was placed on the course to create a surface-contaminant-boot sole condition that would have a consistent static COF. The static COF for this course was in the range of 0.4 to 0.6. This is considered slippery, but it is unlikely to cause test participants to constantly lose their footing and fall. The soil penetration, moisture content, density, and static COF of the mud course are given in Appendix B.

Familiarization

To control for learning effects during the arithmetical and memory tasks, two half-day practice sessions were held to familiarize the test participants with these tests. Also, during the practice sessions, the monitoring task was explained to the participants, but it was not practiced. The arithmetical task and the memory task were presented to the participants as a group in a classroom. The problems and the memory words were read to the participants at the same pace in which they were presented during the data collection trials. In the arithmetical practice session, participants wrote their answers on sheets of paper. For the memory task, participants circled "yes" or "no" on an answer sheet. During the first practice session, three sets of 20 arithmetical problems were presented, and six sets of memory tasks were performed. At the second practice session, three sets of 20 different arithmetical problems and four new sets of memory tasks were completed. In the practice sessions, percent error ranged from 0.0 to 3.33 for

the arithmetical task. The mean error was 0.49% (0.99 SD). For the memory task, error ranged from 0.0% to 8.75%. The mean error was 3.52% (2.85 SD).

Data Collection Trials

In all the data collection trials in this study, participants wore the individual clothing shown in Table 2 and either the fighting load (light load) shown in Table 3 or the existence load (heavy load) shown in Table 4. A data collection trial consisted of answering the cognitive questions and having physiological status measured while one of the loads was carried over one of the test courses. The speed at which test participants carried the load over the course was 1.1 m/s (2.5 mph). The distance they covered in each 1-hour trial was 4.0 km (2.5 mi). A pacing wheel was used to set the speed for the test participants. The speed of 1.1 m/s (2.5 mph) was used because it was thought that this pace would be slow enough for soldiers to walk through the sand course (which was expected to be the most difficult course) without becoming so fatigued that they could not complete two trials in one day. Also, this is the pace Soule and Goldman (1972) used when they determined the terrain coefficients for the equation to predict energy expenditure.

Three cognitive tasks were used in this study. They were administered using auditory presentation through earphones with each stimulus being presented at equal sound levels. The following is a brief description of the three cognitive tasks. Each of the cognitive tasks was counter-balanced to decrease the presence of practice effects. Each cognitive task was tape recorded using the same male voice and presented to the participant through headphones. The test participant responded to the cognitive tasks verbally, and his responses were captured on audiotape.

Arithmetical Task

This task is based on the arithmetical processing subtask of the Criterion Task Set (CTS) Battery which is a battery of standardized tests for assessing a wide range of mental performance skills (Shingledecker, 1984). Test participants solved addition and subtraction equations. Each equation had three terms, and the terms were numbers between 0 and 10 (e.g., 7 + 3 - 4 = ?).

Memory Search Task

This task is based on a technique used by Penney (1989). Test participants were supposed to memorize a list of four words, which was read to them twice. Then they heard a list

of 16 words. After each word, they were supposed to respond "yes" or "no." If the word was one that they were supposed to memorize, they should have responded "yes." If it was not one they were supposed to memorize, they should have answered "no."

Auditory Monitoring Task

Each participant was assigned a call sign (e.g., Zulu 22, Hotel 43, or Alpha 16). Simulated radio traffic was introduced through the headphones. Test participants listened to the radio traffic and responded to messages that included their assigned call sign.

The cognitive tests were administered, starting at the 10th minute of each data collection trial. Test participants answered arithmetical questions from the 10th to the 15th minute. From the 20th to the 35th minute, and again from the 40th to 55th minute, they responded to arithmetical, memory, and monitoring tasks. Cognitive tests began at the 10th minute in order for test participants to become comfortable with the test course, the pace, the load they were carrying, and to allow their bodies to come to a relatively steady state physiologically.

During each trial, physiological measures were taken three times. After test participants began walking, physiological data (VO_2, VE, and HR) were collected during three 5-minute periods from the 15th to 20th, 35th to 40th, and 55th to 60th minutes. Figure 5 shows a test participant during the physiological measurements. The VO_2 and VE data were taken from the Oxylog2® which measured the oxygen content and volume of the test participants' expired air. The HR data came from the heart watch. Following each of the three 5-minute periods, test participants were shown a copy of the Borg scale and asked to provide an RPE.

At the conclusion of the walking task, participants were given the National Aeronautics and Space Administration Task Load Index (NASA TLX) questionnaire (Hart & Staveland, 1988). This questionnaire was used to rate their perceived workload, based upon six sub-categories of workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. A copy of the NASA TLX questionnaire is in Appendix C. There are two parts to the questionnaire. The first part is the Sources of Workload Comparison. The number of times that a sub-category (e.g., mental demand) is chosen determines the weight given to that sub-category. The second part of the questionnaire is the sub-scale rating sheet. It is used to determine the level of demand in each workload sub-category. Each scale on the sub-scale rating sheet represents 100 units (0 to 100 in increments of 5).

Figure 5. Test participant during physiological measurements.

The data collection trials took place 26 May through 4 June 1998 at APG. The trials were conducted during daylight between 9:00 and 16:30 eastern daylight savings time (EDST) except for one trial that began at 7:50 and two trials that ended at 16:45 and 17:20. The participants were divided into three groups of four soldiers. Test participants completed two trials each day their group participated. Water was available for the test participants to drink during the trials. Between trials, participants had time to rest, drink water, and eat. The break between trials was at least 30 minutes, and on days when Groups 2 and 3 participated, the break was approximately 2 to 4 hours. The data collection days alternated so that each group had at least one day of rest between data collection days. Data were collected from Groups 2 and 3 on the same day but not at the same time.

Weather Conditions During Data Collection

In general, the weather during this study was very good. There was no precipitation during the data collection trials. On 29 May, the wet bulb globe temperature (WBGT) reached 26° C (78° F) at 12:15 EDST. However, the WBGT never reached 28° C (82° F). This would have caused testing to be suspended (per the protocol for the experiment) because of concern about heat-related injuries. Meteorological data collected during the study are given in Appendix D.

Soil Conditions During Data Collection

To characterize the terrains that the test participants walked upon, a variety of tests was performed. Soil penetration, soil density, and moisture content tests were performed on the sand and mud courses. Static COF was measured on the mud and blacktop courses. The soil penetrometer and the soil density and moisture content measuring device were used by ATC instrumentation personnel. The friction measurements were made by investigators conducting this study. The terrain characterization data collected during this study are given in Appendix B.

DATA ANALYSIS

Separate analyses of variance (ANOVAs) were conducted for each evaluation (cognitive and physiological). A within-subjects repeated measures ANOVA was conducted on the dependent variables (percent error on the cognitive tests, overall workload based upon the NASA TLX questionnaire, VO_2, VE, HR, and RPE) using the independent variables (load, terrain, and block or time). These analyses included a check for compound symmetry. If the assumption for compound symmetry was violated, then the conservative Greenhouse-Geisser correction for the degrees of freedom was used. The level of significance for these analyses was 0.05. Tukey's Honestly Significant Difference (HSD) Test was used to determine significant differences among the means.

Test participants' responses to the arithmetical, memory, and monitoring tasks were recorded from the audiotapes into spreadsheets. Data were separated into three separate spreadsheets, one for each type of task. The data from each task were further divided into blocks. The arithmetical task had a total of ten blocks of ten questions, the memory task had four blocks of 32 questions, and the monitoring task had two blocks of 36 questions. The blocks for each of the tasks were taken from different points in time along the march (see Table 5). For each block, the percent error was calculated by dividing the number of incorrect responses by the total number of questions.

Table 5

Times When Cognitive Tasks Occurred

Task	Block	Average time block occurred (mm:ss)
Arithmetic	1-4	10:15 to 14:09
Memory	1	21:18 to 23:59
Arithmetic	5-6	24:12 to 25:44
Monitoring	1	25:57 to 30:27
Memory	2	30:42 to 33:21
Arithmetic	7	33:36 to 34:21
Memory	3	41:16 to 43:55
Arithmetic	8-9	44:10 to 45:45
Monitoring	2	45:58 to 50:33
Memory	4	50:48 to 53:29
Arithmetic	10	53:41 to 54:23

The overall workload from the NASA-TLX for each trial was used in the analysis. Overall workload is the sum of each sub-category's score (from the sub-scale rating sheet) multiplied by its weight (from the Sources of Workload Comparison) and divided by 15 (the sum of the weights).

In the analysis of the physiological data, the mean VO_2, VE, and HR for each data collection period (15, 35, and 55 minutes, respectively) were used.

RESULTS

Cognitive Tasks

The results of the analysis for the cognitive tasks are shown in Table 6 and Appendix E. Table 7 shows the percent error for the monitoring task for each terrain, load, and block. The overall mean error for the monitoring task was 1.7%. The analysis showed a Load x Block interaction $F(1,11) = 7.72$, $p = 0.018$ for the monitoring task. A Tukey's HSD Test was performed, and the results indicate that in Block 2, the light load condition had a significantly lower error rate than did the heavy load condition (see Figure 6). The light load condition in Block 2 also had a significantly lower error rate than did either load condition in Block 1.

Table 6

Results From Cognitive Task Data Analysis

Variable	Effect	F-ratio	*p*-value
Percent error arithmetical task	Terrain	F(2,22) = 0.13	ns
	Load	F(1,11) = 0.13	ns
	Block	F(4,44) = 1.21	ns
	Terrain x Load	F(2,22) = 0.52	ns
	Terrain x Block	F(8,88) = 0.65	ns
	Load x Block	F(4,44) = 1.25	ns
	Terrain x Load x Block	F(8,88) = 0.67	ns
Percent error memory task	Terrain	F(2,22) = 0.20	ns
	Load	F(1,11) = 1.13	ns
	Block	F(3,33) = 1.82	ns
	Terrain x Load	F(2,22) = 2.09	ns
	Terrain x Block	F(6,66) = 1.17	ns
	Load x Block	F(3,33) = 1.76	ns
	Terrain x Load x Block	F(6,66) = 1.48	ns
Percent error monitoring task	Terrain	F(2,22) = 1.38	ns
	Load	F(1,11) = 0.77	ns
	Block	F(1,11) = 1.43	ns
	Terrain x Load	F(2,22) = 0.18	ns
	Terrain x Block	F(2,22) = 1.48	ns
	Load x Block*	F(1,11) = 7.72	*p*=.018
	Terrain x Load x Block	F(2,22) = 3.04	ns

*indicates significance

Table 7

Percent Error for the Monitoring Task
Mean (SD)

Block	Blacktop light	Blacktop heavy	Sand light	Sand heavy	Mud light	Mud heavy
1	2.1 (2.9)	3.2 (7.9)	1.2 (1.9)	0.2 (8.0)	3.0 (7.3)	1.6 (2.2)
2	0.3 (.81)	3.7 (6.5)	0.2 (0.8)	1.4 (2.7)	2.3 (6.4)	0.9 (1.8)

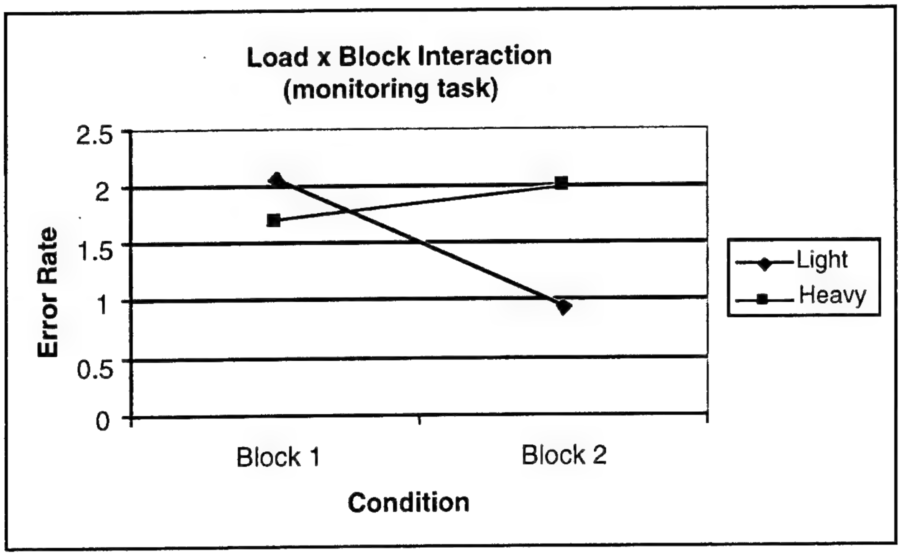

Figure 6. Load x Block interaction (monitoring task).

The results indicate no significant differences for main effects or interactions for the arithmetical and memory tasks. The overall mean error for the arithmetical task was 13.5%. Table 8 shows the percent error for the arithmetical task for each terrain, load, and block. The overall mean error for the memory task was 8.2%. Table 9 shows the percent error for the memory task for each terrain, load, and block.

Table 8

Percent Error for the Arithmetical Task
Mean (SD)

Block	Blacktop light	Blacktop heavy	Sand light	Sand heavy	Mud light	Mud heavy
1	16.7 (16.7)	9.2 (12.4)	15.0 (22.0)	15.8 (22.3)	18.3 (19.5)	17.5 (19.6)
2	11.7 (13.4)	10.8 (17.3)	15.8 (22.3)	8.3 (9.4)	15.8 (19.8)	8.3 (17.5)
3	14.2 (21.1)	9.2 (12.4)	8.3 (14.0)	8.3 (11.2)	14.2 (25.4)	12.5 (19.1)
4	6.7 (8.9)	17.5 (20.9)	11.7 (19.5)	14.2 (19.3)	18.3 (28.6)	11.7 (16.4)
5	16.7 (16.1)	15.8 (25.0)	13.3 (16.7)	10.0 (9.5)	15.0 (13.8)	10.0 (15.4)
6	17.5 (24.9)	16.7 (16.7)	11.7 (14.7)	14.2 (16.8)	16.7 (20.6)	12.5 (19.6)
7	15.0 (27.8)	15.8 (22.8)	20.8 (22.8)	15.8 (22.8)	14.2 (22.8)	12.5 (15.5)
8	20.0 (23.0)	12.5 (17.7)	9.2 (12.4)	15.8 (25.4)	11.7 (11.2)	9.2 (14.4)
9	15.8 (20.2)	19.2 (20.2)	9.2 (10.8)	15.8 (31.5)	15.8 (18.3)	11.7 (19.5)
10	4.2 (6.7)	17.5 (22.2)	9.2 (9.0)	15.0 (23.2)	11.7 (17.0)	13.3 (16.7)

Table 9

Percent Error for the Memory Task
Mean (SD)

Block	Blacktop light	Blacktop heavy	Sand light	Sand heavy	Mud light	Mud heavy
1	6.8 (7.2)	9.4 (9.0)	11.2 (6.3)	7.0 (6.4)	11.5 (10.4)	6.5 (5.6)
2	6.3 (9.6)	7.3 (10.7)	2.9 (3.1)	6.5 (7.9)	8.3 (9.6)	8.9 (10.3)
3	6.0 (5.4)	11.7 (11.2)	9.4 (15.1)	12.5 (14.6)	11.7 (12.0)	6.5 (7.2)
4	5.5 (6.7)	7.3 (4.7)	7.8 (16.4)	14.1 (17.2)	5.7 (9.3)	5.2 (5.7)

NASA TLX Data

The results of the analysis for the NASA TLX questionnaire data are shown in Table 10 and Appendix C. These results indicate a main effect of load. No significant interactions were found. Table 11 shows the workload rating for each terrain and load.

Table 10

Results From NASA TLX Data Analysis

Variable	Effect	F-ratio	*p*-value
Overall workload	Terrain	$F(2,22) = 0.33$	ns
	Load*	$F(1,11) = 11.70$	$p=.006$
	Terrain x Load	$F(2,22) = 0.05$	ns

*indicates significance

Table 11

NASA TLX Questionnaire Results
NASA TLX Workload Ratings Mean (SD)

Blacktop light	Blacktop heavy	Sand light	Sand heavy	Mud light	Mud heavy
38.4 (24.1)	52.2 (19.5)	38.6 (16.3)	54.7 (20.8)	39.6 (22.8)	54.8 (22.3)

Physiological Data

The results of the analysis for the physiological data showed significant main effects of terrain, load, and time for all the variables (VO_2, VE, HR, and RPE). Results are shown in Tables 12 and 13 and Appendix E. For all the variables, carrying the heavy load is significantly different than carrying the light load; VO_2, VE, HR, and RPE are all higher. With regard to terrain, the results for the sand and mud conditions are significantly higher than the results for the blacktop condition. However, for VO_2, VE, and RPE, the results for the sand and mud conditions are not significantly different. All the variables show a significant increase with respect to time.

Table 12

Results From Physiological Data Analysis

Variable	Effect	F-ratio	*p*-value
VO_2	Terrain*	F(2,20) = 36.15	*p* =.000
	Load*	F(1,10) = 51.58	*p* =.000
	Time*	F(2,20) = 12.71	*p* =.000
	Terrain x Load	F(2,20) = 1.65	ns
	Terrain x Time	F(4,40) = 0.84	ns
	Load x Time*	F(2,20) = 6.45	*p* =.007
	Terrain x Load x Time	F(4,40) = 0.69	ns
Ventilation	Terrain*	F(2,20) = 16.35	*p* =.000
	Load*	F(1,10) = 54.36	*p* =.000
	Time*	F(2,20) = 30.69	*p* =.000
	Terrain x Load	F(2,20) = 1.57	ns
	Terrain x Time*	F(4,40) = 3.92	*p* =.009
	Load x Time	F(2,20) = 0.52	ns
	Terrain x Load x Time	F(4,40) = 0.92	ns
Heart rate	Terrain*	F(2,20) = 22.98	*p* =.000
	Load*	F(1,10) = 22.28	*p* =.001
	Time*	F(2,20) = 38.82	*p* =.000
	Terrain x Load	F(2,20) = 0.51	ns
	Terrain x Time*	F(4,40) = 16.07	*p* =.000
	Load x Time*	F(2,20) = 4.17	*p* =.030
	Terrain x Load x Time	F(4,40) = 0.34	ns
RPE	Terrain*	F(2,20) = 7.10	*p* =.004
	Load*	F(1,10) = 35.87	*p* =.000
	Time*	F(2,20) = 38.67	*p* =.000
	Terrain x Load	F(2,20) = 0.40	ns
	Terrain x Time	F(4,40) = 1.21	ns
	Load x Time*	F(2,20) = 5.97	*p* =.009
	Terrain x Load x Time	F(4,40) = 0.71	ns

*indicates significance

Table 13

Mean Values for the Physiological Data

Time	Blacktop light	Blacktop heavy	Sand light	Sand heavy	Mud light	Mud heavy
			VO_2 (l/min) Mean (SD)			
15-30	1.1 (0.2)	1.2 (0.2)	1.6 (0.2)	1.7 (0.2)	1.5 (0.2)	1.7 (0.3)
35-40	1.1 (0.2)	1.3 (0.2)	1.6 (0.3)	1.8 (0.3)	1.6 (0.3)	1.8 (0.3)
55-60	1.2 (0.2)	1.3 (0.2)	1.7 (0.3)	1.8 (0.3)	1.6 (0.3)	1.8 (0.3)
			VE (l/min BTPS) Mean (SD)			
15-30	27.8 (3.5)	30.9 (7.8)	36.3 (5.7)	40.1 (5.7)	33.8 (5.2)	40.5 (7.3)
35-40	28.8 (4.8)	32.4 (7.9)	37.2 (5.6)	42.6 (6.3)	34.1 (5.9)	40.5 (7.9)
55-60	29.6 (5.5)	32.7(7.4)	39.0 (6.8)	43.9 (6.4)	34.7 (5.9)	41.7 (7.9)
			HR (beats/min) Mean (SD)			
15-30	109.6 (10.7)	114.4 (15.2)	127.6 (14.3)	136.5 (10.7)	120.2 (11.4)	128.3 (10.3)
35-40	109.9 (10.0)	116.9 (15.4)	133.3 (14.4)	142.5 (12.5)	121.4(11.5)	131.0 (11.3)
55-60	110.5 (11.4)	116.9 (14.7)	136.7 (15.8)	147.8 (13.2)	123.1 (11.2)	132.9 (11.3)
			RPE Mean (SD)			
15-30	7.9 (1.7)	10.4 (2.4)	9.0 (1.9)	12.3 (1.5)	8.8 (1.9)	11.8 (2.2)
35-40	8.4 (1.9)	11.3 (2.6)	10.2 (2.2)	13.8 (2.5)	10.0 (1.9)	12.9 (2.5)
55-60	8.8 (1.9)	12.3 (2.2)	10.5 (2.3)	14.3 (1.9)	10.4 (1.6)	13.8 (2.6)

In addition to these main effects, the data analysis also revealed several interactions. The analysis of the VO_2 data showed a significant Load x Time interaction $F(2,20) = 6.45$, $p = .007$. Tukey's HSD Test conducted on the Load x Time interaction showed that for the heavy load, VO_2 increased at each point in time, but there was no significant difference over time for the light load (see Figure 7).

The VE data indicate a significant Terrain x Time interaction for two of the conditions (see Figure 8). For the blacktop condition, Tukey's HSD Test revealed a significant increase in VE between 15 and 35 minutes. For the sand condition, Tukey's HSD Test revealed a significant increase in VE between 15 and 35 minutes. No significant differences were found for the mud condition.

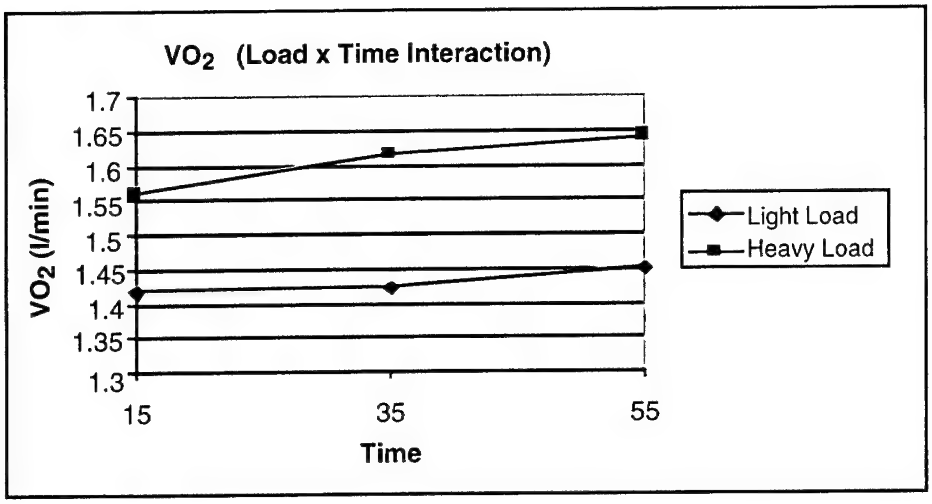

Figure 7. Load x Time interaction (VO_2).

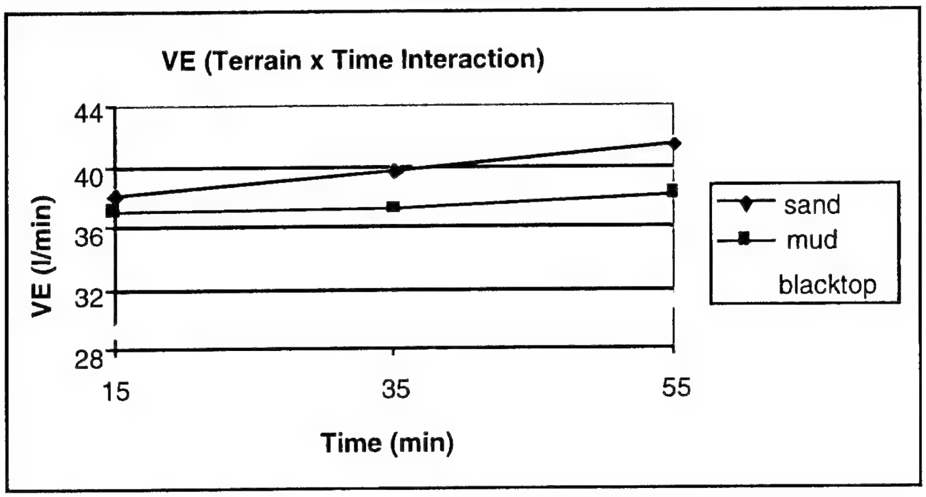

Figure 8. Terrain x Time interaction (VE).

The HR data show a significant Load x Time interaction. Tukey's HSD Test performed on the Load x Time interaction showed significant increases in HR for both load conditions between each time (see Figure 9).

The HR data also show a significant Terrain x Time interaction (see Figure 10). Tukey's HSD Test performed on the Terrain x Time interaction showed significant increases in HR across all times for the sand condition, significant increases in HR between 15 and 55 minutes for the mud condition, and no change in HR across time for the blacktop condition.

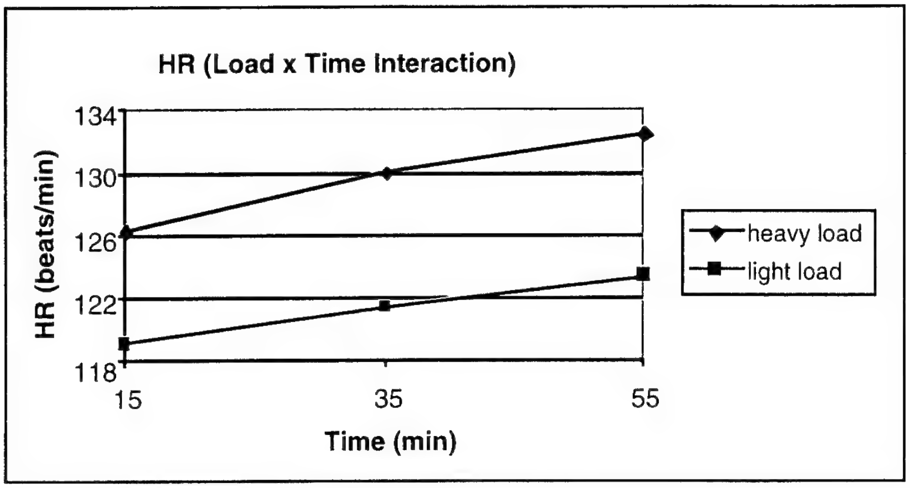

Figure 9. Load x Time interaction (HR).

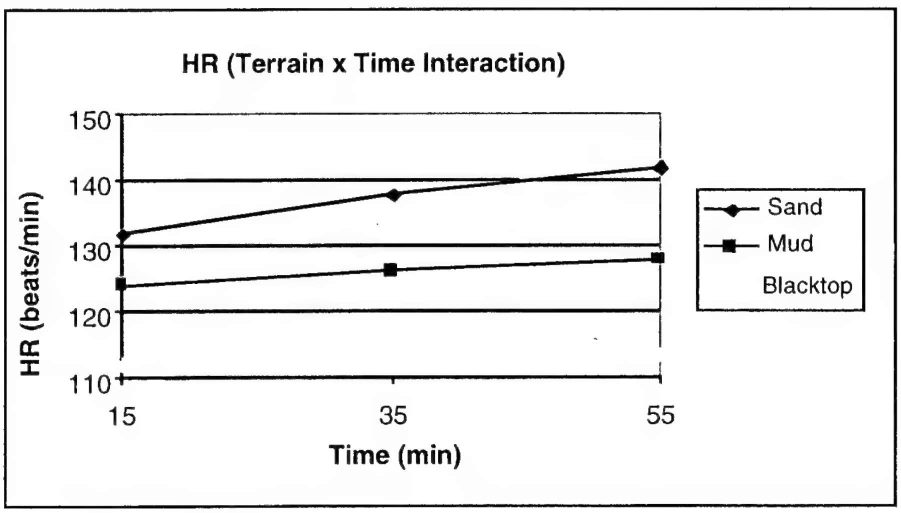

Figure 10. Terrain x Time interaction (HR)

The RPE data show a significant Load x Time interaction. Tukey's HSD Test conducted on the Load x Time interaction showed significant differences in RPE for the heavy load at all three times. The light load showed significant differences between 15 and 35 minutes and between 15 and 55 minutes (see Figure 11).

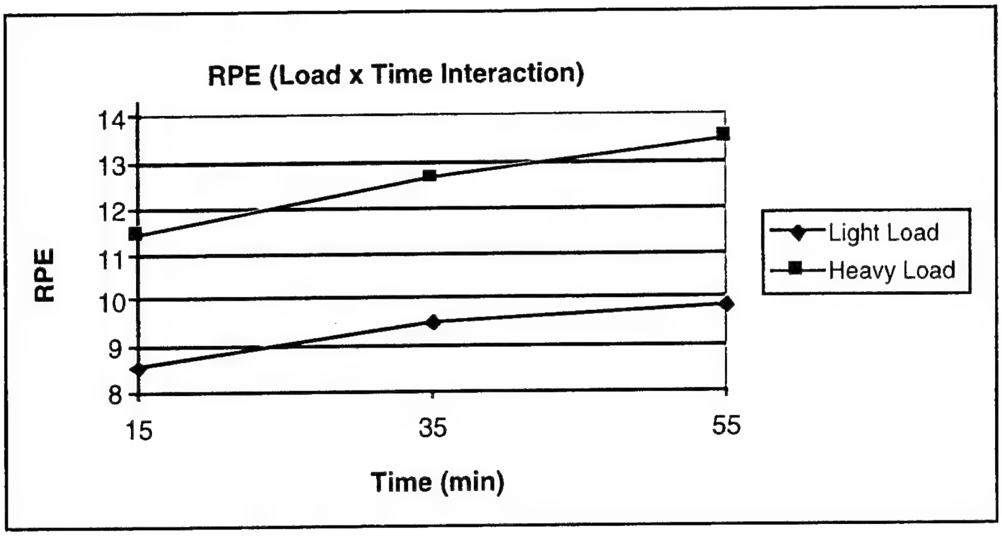

Figure 11. Load x Time interaction (RPE).

DISCUSSION

Cognitive Data

As presented in the results section, there is a Load x Block interaction for the monitoring task. Performance of the monitoring task improved over time when the light load was carried. The improved performance of the monitoring task is evidence of a beneficial relationship between exercise and cognitive performance. Several of the studies cited previously (Lybrand et al., 1954; Burgess & Hokanson, 1964; Davey, 1973; McGlynn et al., 1977; Gliner et al., 1979; Hogervorst et al., 1996) found a beneficial realtionship between exercise and cognitive performance. Carrying the light load may cause an exercise-induced increase in alertness which results in improved performance of the monitoring task.

The existence of a Load x Block interaction for the monitoring task has important implications for soldiers performing tasks such as monitoring a radio while road marching. These implications raise questions that will require further research to answer. The questions are (a) What is the optimal load for achieving maximum performance on a monitoring task? (b) If the march continues for several hours, is the increased performance of the monitoring task maintained?

No significant differences were shown for the arithmetical and memory tasks. As discovered in the studies by Tomporowski et al. (1985) and Zervas (1990), exercise had no effect on performance of these tasks. This may be because of the structured presentation of the

questions, the method of presentation (one cognitive task at a time), the fact that the soldiers were well trained before the data collection trials began, or the physical exertion may not have been intense enough to affect cognitive performance. Further research will be needed to determine why there were no significant differences for the arithmetical and memory tasks.

NASA TLX Data

As shown in the results, there was a significant difference between the overall workload ratings for the light and heavy load conditions. Test participants perceived that carrying the heavy load during the data collection trials significantly contributed to their workload. It is expected that workload would be higher for the heavy load condition because carrying a heavy load is more physically demanding than carrying a light load. However, it is interesting to note that terrain did not significantly affect the overall workload ratings. Terrain was a significant effect for all the physiological variables, but test participants did not perceive that terrain affected their workload during the conditions of this study.

Physiological Data

Overall, the results of this study are consistent with normal physiological responses to walking while carrying loads. Terrain, load, and time influence energy expenditure (VO_2). As mentioned in the results, the sand condition showed the highest VO_2. This effect of terrain on VO_2 has been documented in the literature. Soule and Goldman (1972) examined the effect of terrain and load carriage on energy expenditure. They investigated walking over different terrains (blacktop, dirt road, light brush, heavy brush, swamp, and sand) and concluded that at a given speed, the different terrains generally required significantly different energy expenditures. The blacktop road showed the lowest energy expenditure for each of the load conditions and the sand showed the highest. The results of the present study are consistent with the results of Soule and Goldman (1972).

Studies by Givoni and Goldman (1971) and Pandolf, Givoni, and Goldman (1977) have shown that energy expenditure during walking increases as the load being carried increases. In the present study, the energy expenditure, as measured by VO_2, for the heavy load was significantly greater than the energy expenditure for the light load. This is consistent with the results published in the literature.

Results from this study indicated that energy expenditure is not constant but increases significantly over time during prolonged load carriage. This is consistent with the results of studies by Epstein, Rosenblum, Burstein, and Sawka (1988) and Patton, Kaszuba, Mello, and Reynolds (1991). These studies found that energy expenditure during load carriage increases significantly over time.

Physiological Performance on Slippery Terrain

As previously mentioned, Soule and Goldman (1972) examined load carriage over many terrains. However, the effects of slippery terrain have not been specifically examined. Therefore, it is not possible to compare energy expenditure data from the mud condition in the present study with energy expenditure data from other studies. It is interesting to note that there is no statistically significant difference between the energy expenditure for the mud and sand conditions. The overall mean VO_2 was 1.7 l/min for the sand condition and 1.7 l/min for the mud condition.

In this study, the blacktop road was the baseline condition. There are several reasons why energy expenditure for the sand and mud conditions are higher (approximately 40%) than the energy expenditure for the blacktop road condition. As a result of the soldiers' sinking into the sand with each step, the energy expenditure for walking in the sand condition is probably higher because the test participants' center of gravity moves a greater vertical distance in this condition. Also, the push-off forces are probably different because the sand is loose and does not provide firm footing. For the mud condition, although test participants sank into the mud slightly, other factors probably contributed to the increase in energy expenditure. Additional muscular force is required to overcome the suction force of the mud on the soldiers' boots. Also, slipping, uncertainty about slipping and therefore careful foot placement, and the additional weight of mud clinging to the soldiers' boots probably contributed to the increase in energy expenditure in comparison to the blacktop road condition.

Enhancements of Existing Modeling Tools

The improved performance research integration tool (IMPRINT) and the integrated unit simulation system (IUSS) are two modeling tools that are currently used to predict performance of individual soldiers. Models developed in IMPRINT focus more on cognitive performance than on physiological performance, whereas models developed in IUSS focus more on physiological performance than on cognitive performance. These models are used to support the research, development, and acquisition of materiel for the Army by assessing soldier-system performance.

Although it is beyond the scope of this report, there are two ways that the data collected in this study can be used to enhance models such as IMPRINT and IUSS. The first way is to validate models created by these tools. If an IMPRINT or IUSS task similar to the tasks that the test participants performed in this study exists, then the output of the simulation can be compared to the data collected in this study. The second way to enhance IMPRINT and IUSS with the data collected in this study is to develop algorithms that describe a soldier's cognitive or physiological performance. For example, three of the tasks performed in this study (carrying a load, the arithmetical task, and the monitoring task) match three of the taxons (i.e., categories) used in IMPRINT to describe tasks: gross motor, numerical, and communication, respectively. Algorithms that describe a soldier's performance of these tasks could be developed and incorporated into IMPRINT after appropriate verification and validation.

CONCLUSIONS

The first hypothesis of this study is that there will be no difference in cognitive performance as a function of load carried. The Load x Block interaction for the monitoring task shows that there is a difference in performance as a function of load carried and time at which the task is performed. Therefore, for the monitoring task, Hypothesis 1 is rejected. Based upon the methodology of this study, Hypothesis 1 is accepted for the arithmetical and memory tasks.

The second hypothesis of this study is that there will be no difference in cognitive performance as a function of terrain traversed. There were no statistically significant differences in performance of the arithmetical, memory, or monitoring tasks. Therefore, for the conditions of this study, Hypothesis 2 is accepted.

With regard to the physiological results, as expected, Hypotheses 3 and 4 are rejected. There are differences in physiological performance (VO_2, VE, HR, and RPE) as a function of both load carried and terrain traversed. Interestingly, this study found that the energy expenditure for walking on slippery terrain (mud) is the same as the energy expenditure for walking on loose sand.

Based upon the NASA TLX questionnaire data, it is the load that the soldiers are carrying rather than the terrain they are traversing that causes the significant increases in subjective assessment of workload.

RECOMMENDATIONS

More research needs to be done to thoroughly understand the combined cognitive and physiological performance of soldiers carrying loads over various terrains. This research should be conducted in steps. The first step should be to determine why there was a significant difference between the light and heavy loads at Block 2 for the monitoring task and how this difference can influence soldier-system performance. The second step should be to determine if the combination of various other cognitive measures (decision-making tasks and multiple tasks that must be done simultaneously) and a more strenuous physical component (a variety of speeds, grades, and unpredictable terrain) influences performance. These tasks can then be used to examine cognitive and physiological performance during conditions that are more realistic for soldiers. The third step should be to examine how other factors such as sleep deprivation, darkness, environmental noise, harsh weather (extremes of cold or heat, rain, and snow), and stress influence cognitive and physiological performance.

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APPENDIX A

LOAD CARRIAGE EXPERIENCE QUESTIONNAIRE

LOAD CARRIAGE EXPERIENCE QUESTIONNAIRE

Name: ______________________________

1 When was the last time you wore an LCE for an hour or more?
Month: ________ Year: ________

2 Approximately, how much did it weigh? ____________

3 What was in the LCE?

____

____

4 When was the last time you carried an ALICE pack or a recreational backpack for an hour or more? Month: ________ Year: ________

5 Approximately, how much did it weigh? ____________

6 What was in the pack?

____

____

____

7 Within the past year, how many times have you worn an LCE for an hour or more?

____

8 Within the past year, how many times have you carried an ALICE pack or a recreational backpack for an hour or more? ________

9 How far did you march/hike with it each time?

____

____

APPENDIX B

CHARACTERIZATION OF THE SAND, MUD, AND BLACKTOP ROAD COURSES

CHARACTERIZATION OF THE SAND, MUD, AND BLACKTOP ROAD COURSES

During this study, the soils at the sand course and the mud course remained fairly consistent. Figure B-1 shows the sand course, and Figure B-2 shows the mud course. The locations at which soil measurements were made at each course are shown on the figures. Table B-1 contains the soil data collected at each course. The static COF measurements are shown in Table B-2.

The data in Table B-1 show that the sand course dried slightly from 27 May to 28 May. The slight increase in moisture content at the sand course on 3 June is probably the result of rain, 1.14 cm (0.45 in), on 1 June. On 3 June, the mud course penetrometer readings at 1 inch are nearly the same as the mud course penetrometer readings at 3 inches on 29 May. This is probably because some of the loose, fine soil in the mud washed away during the rain on 1 June. Also, to maintain the consistency of the mud, water was sprayed on the mud course in the afternoon on 1 June and 3 June. This probably contributed to the soil erosion, too.

Throughout the data collection trials, slippery conditions were maintained on the mud course (see Table B-2). The static COF was in the range of 0.4 to 0.5, which is considered slippery (Swensen, Purswell, Schlegel, & Stanevich, 1992). Table B-2 also contains static COF data from the blacktop road.

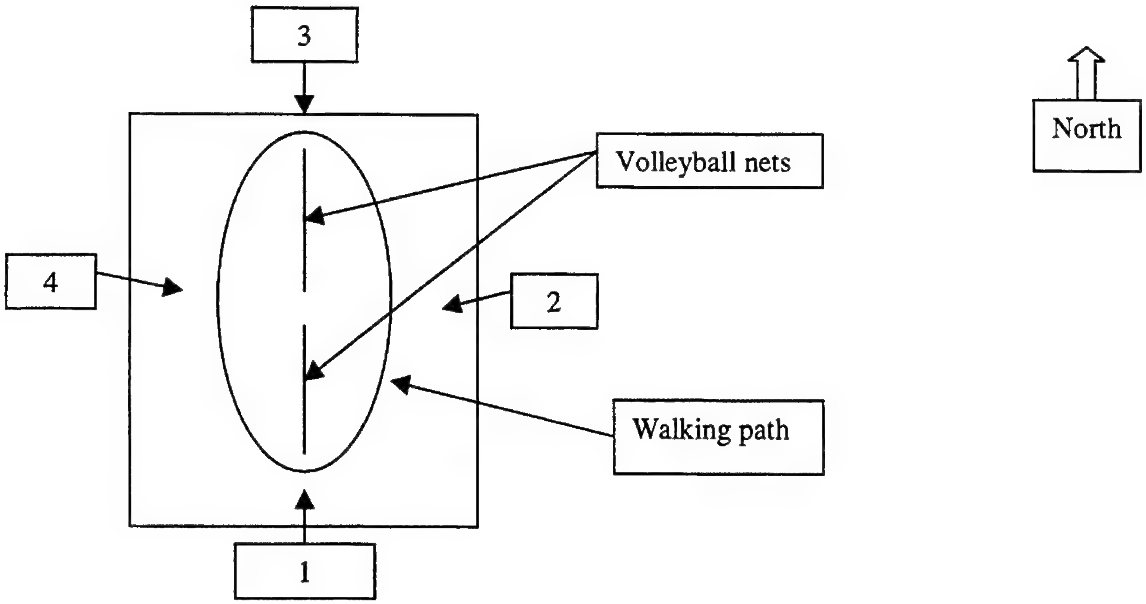

Figure B-1. Sand course.

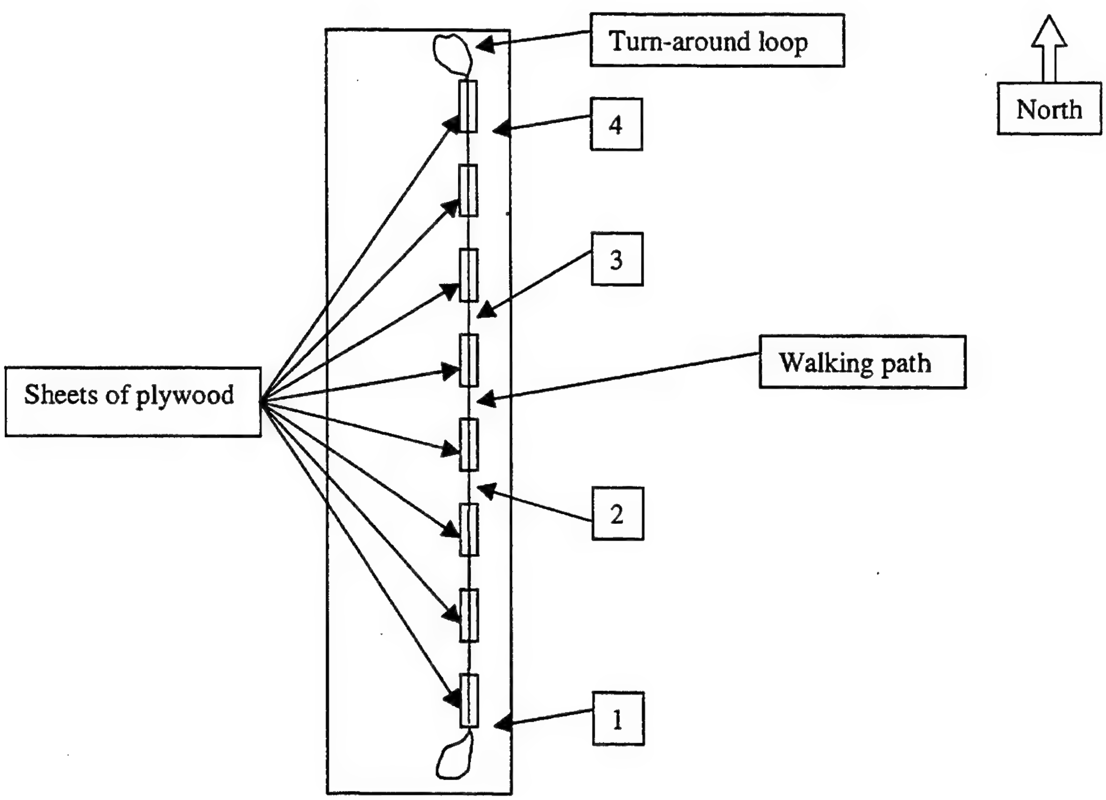

Figure B-2. Mud course.

Table B-1

Soil Data

Date	AM/PM	Course	Position	Bulk density (lb/ft^3)	Dry density (lb/ft^3)	Percent moisture	Penetrometer
5/27/98	AM	Sand	1	98.07	93.64	4.734	-
			2	99.23	94.06	5.504	-
			3	96.09	92.12	4.308	-
			4	101.2	95.39	6.109	-
5/27/98	PM	Sand	1	96.93	92.76	4.503	-
			2	95.16	89.92	5.830	-
			3	99.36	95.07	4.518	-
			4	101.3	96.56	4.979	-
5/28/98	AM	Sand	1	94.58	91.03	3.894	-
			2	98.26	93.34	5.278	-
			3	99.97	95.80	4.360	-
			4	92.65	86.86	6.672	-
5/29/98	PM	Mud	1	130.5	118.8	9.894	150 @ 3"
			2	136.0	122.8	10.69	130 @ 3"
			3	133.3	121.3	9.851	110 @ 3"
			4	129.4	116.3	11.25	130 @ 3"
6/1/98	AM	Mud	1	130.5	116.8	11.78	-
			2	126.4	114.5	10.43	-
			3	124.1	109.3	14.11	-
			4	115.9	99.48	16.54	-
6/1/98	PM	Mud	1	133.1	118.1	12.65	
			2	128.8	116.4	10.67	
			3	129.1	115.2	12.08	
			4	122.8	103.4	18.80	
6/3/98	AM	Sand	1	99.45	94.25	5.520	45 @ 1", 150 @ 3", 300 @ 6"
			2	97.84	90.63	7.962	35 @ 1", 145 @ 3", 300 @ 6"
			3	97.13	91.85	5.750	20 @ 1", 120 @ 3", 300 @ 6"
			4	102.6	95.77	7.163	45 @ 1", 160 @ 3", 300 @ 6"
6/3/98	PM	Mud	1	121.8	110.4	10.28	140 @ 1", 300 @ 2"
			2	120.4	108.3	11.10	110 @ 1", 300 @ 2"
			3	125.2	110.2	13.59	140 @ 1", 300 @ 2"
			4	126.9	113.4	11.82	50 @ 1", 300 @ 2"

Table B-2

Static Coefficient of Friction

Date	Location	Friction force (lb) Trial 1	Trial 2	Trial 3	Mean	Static COF
5/29/98	Mud near positions 2 and 3	14.35	22.45	20.35	19.05	0.61
5/29/98	Mud on plywood (0.5 inch thick) near positions 2 and 3	14.00	11.35	13.50	12.95	0.42
6/1/98	Mud near positions 2 and 3	14.85	9.85	8.80	11.17	0.36
6/1/98	Mud near positions 2 and 3	13.45	12.55	11.75	12.59	0.41
6/2/98	Blacktop Road	41.75	46.20	43.55	43.84	1.41

Note: Static COF is determined from the equation Static COF=F_f/N. F_f is the friction force in pounds. N is 31 lb, which is the weight of the concrete-filled boots, the wooden framework, and the steel weight.

APPENDIX C

NASA TLX QUESTIONNAIRE

NASA TLX QUESTIONNAIRE

NASA TLX—Sources of Workload Comparison

SUBJECT ID: ____________________ TASK ID: __________________

Sources of workload comparison.

Please circle one factor out of two presented, for each item, that caused more workload in the task.

1.	Effort	or	Performance
2.	Temporal Demand	or	Frustration
3.	Temporal Demand	or	Effort
4.	Physical Demand	or	Frustration
5.	Performance	or	Frustration
6.	Physical Demand	or	Temporal Demand
7.	Physical Demand	or	Performance
8.	Temporal Demand	or	Mental Demand
9.	Frustration	or	Effort
10.	Performance	or	Mental Demand
11.	Performance	or	Temporal Demand
12.	Mental Demand	or	Effort
13.	Mental Demand	or	Physical Demand
14.	Effort	or	Physical Demand
15.	Frustration	or	Mental Demand

NASA TLX - Sub Scale Rating Sheet

SUBJECT ID: ____________________ TASK ID: ____________________

Ratings of specific workload sub scale.

Please rate the task by placing an "X" on the line that reflects the level of demand for each workload sub-category.

MENTAL DEMAND

Low **High**

PHYSICAL DEMAND

Low **High**

TEMPORAL DEMAND

Low **High**

PERFORMANCE

Good **Poor**

EFFORT

Low **High**

FRUSTRATION

Low **High**

APPENDIX D

METEOROLOGICAL DATA

METEOROLOGICAL DATA

Date	Time (EDST)	Avg Wd Dir (°)	Avg Wd Spd (M/S)	Avg SDWdD (°)	Peak W Spd (M/S)	Avg A Temp (°C)	Max A Temp (°C)	Min A Temp (°C)	Avg Rl Hum (%)	Avg Sl Rad (W/M^2)	Tot Precp (")	Avg Press (MB)
5/26/98	7:00	268	0.836	4	1.137	17.8	17.9	17.8	87	59.1	0.00	1008.9
5/26/98	7:15	286	0.988	14	1.411	18.1	18.4	17.9	87	82.8	0.00	1009.0
5/26/98	7:30	305	0.940	16	1.842	18.6	18.8	18.3	84	118.4	0.00	1009.0
5/26/98	7:45	317	1.169	19	2.666	19.2	19.7	18.7	79	210.3	0.00	1009.1
5/26/98	8:00	303	1.686	19	2.960	20.1	20.5	19.7	70	262.9	0.00	1009.1
5/26/98	8:15	289	2.020	18	3.861	20.7	21.1	20.4	66	377.7	0.00	1009.1
5/26/98	8:30	311	2.355	21	4.292	21.3	21.6	21.1	64	427.1	0.00	1009.1
5/26/98	8:45	319	2.783	24	6.194	21.8	22.0	21.5	61	498.9	0.00	1009.1
5/26/98	9:00	338	3.495	24	6.429	21.8	21.9	21.6	60	550.7	0.00	1009.1
5/26/98	9:15	340	4.224	20	6.468	21.6	21.8	21.4	54	600.9	0.00	1009.3
5/26/98	9:30	327	3.171	24	5.860	21.8	22.2	21.5	53	656.1	0.00	1009.3
5/26/98	9:45	338	3.343	22	5.841	22.1	22.3	22.0	52	710.6	0.00	1009.4
5/26/98	10:00	338	3.251	22	5.547	22.3	22.5	22.1	51	755.4	0.00	1009.5
5/26/98	10:15	321	2.852	29	5.214	22.4	22.6	22.3	49	792.6	0.00	1009.5
5/26/98	10:30	301	2.527	33	4.978	22.8	23.0	22.6	49	824.0	0.00	1009.4
5/26/98	10:45	332	2.666	22	4.802	23.0	23.2	22.9	48	871.0	0.00	1009.4
5/26/98	11:00	312	2.516	27	4.586	23.3	23.6	23.1	49	894.0	0.00	1009.4
5/26/98	11:15	352	2.384	30	4.096	23.6	23.8	23.4	48	949.0	0.00	1009.4
5/26/98	11:30	304	3.015	35	5.390	23.7	24.0	23.5	48	957.0	0.00	1009.4
5/26/98	11:45	288	2.888	45	6.194	23.8	24.0	23.6	47	1023.0	0.00	1009.5
5/26/98	12:00	312	2.492	35	4.626	24.2	24.5	23.9	47	953.0	0.00	1009.6
5/26/98	12:15	302	3.437	24	6.194	23.8	24.3	23.4	47	769.7	0.00	1009.6
5/26/98	12:30	316	2.447	29	4.841	23.9	24.1	23.5	47	735.1	0.00	1009.5
5/26/98	12:45	314	3.046	36	5.625	23.6	24.1	23.2	48	900.0	0.00	1009.3
5/26/98	13:00	286	2.967	28	6.390	24.2	24.4	24.0	46	997.0	0.00	1009.2
5/26/98	13:15	316	3.241	36	5.743	24.3	24.7	24.1	46	914.0	0.00	1009.2
5/26/98	13:30	314	3.344	26	7.350	24.3	24.6	23.9	46	792.1	0.00	1009.1
5/26/98	13:45	337	3.262	31	5.508	24.4	24.6	24.0	47	1052.0	0.00	1009.2
5/26/98	14:00	313	3.368	28	6.390	24.7	25.0	24.4	47	962.0	0.00	1009.3
5/26/98	14:15	318	3.824	27	7.605	24.4	24.8	23.8	47	737.2	0.00	1009.4
5/26/98	14:30	313	3.727	25	6.468	24.2	24.4	23.8	47	866.0	0.00	1009.6
5/26/98	14:45	334	3.576	20	6.468	24.4	24.6	24.3	47	995.0	0.00	1009.7
5/26/98	15:00	323	3.753	27	6.723	24.5	24.6	24.3	46	944.0	0.00	1009.8
5/26/98	15:15	326	3.600	24	6.958	24.6	24.7	24.4	47	878.0	0.00	1009.7
5/26/98	15:30	338	3.459	24	6.801	24.4	24.6	23.9	47	609.2	0.00	1010.0
5/26/98	15:45	315	3.757	35	7.076	24.3	24.5	23.9	47	802.0	0.00	1010.0
5/26/98	16:00	310	3.247	26	6.311	24.3	24.6	24.1	46	612.3	0.00	1009.8
5/26/98	16:15	307	3.019	24	6.860	24.5	24.6	24.3	46	646.8	0.00	1009.8
5/26/98	16:30	317	2.799	20	5.802	24.6	24.7	24.5	45	629.7	0.00	1010.0

Date	Time (EDST)	Avg Wd Dir (°)	Avg Wd Spd (M/S)	Avg SDWdD (°)	Peak W Spd (M/S)	Avg A Temp (°C)	Max A Temp (°C)	Min A Temp (°C)	Avg Rl Hum (%)	Avg Sl Rad (W/M2)	Tot Precp (")	Avg Press (MB)
5/26/98	16:45	302	3.159	23	7.076	24.6	24.9	24.5	45	580.4	0.00	1010.0
5/26/98	17:00	309	2.605	25	4.704	24.8	24.9	24.6	45	519.3	0.00	1010.2
5/26/98	17:15	322	2.315	23	4.038	24.5	24.9	24.0	45	288.0	0.00	1010.4
5/26/98	17:30	308	2.115	19	4.136	24.0	24.1	23.9	45	290.5	0.00	1010.5
5/26/98	17:45	318	1.701	17	3.214	23.9	24.1	23.7	45	191.4	0.00	1010.5
5/26/98	18:00	304	1.590	17	2.920	23.6	23.7	23.5	45	154.3	0.00	1010.5
5/27/98	7:00	341	0.808	82	1.764	16.2	16.4	16.1	96	41.5	0.00	1014.5
5/27/98	7:15	142	0.254	47	0.666	16.6	16.8	16.4	95	56.8	0.00	1014.6
5/27/98	7:30	76	0.394	31	0.627	17.0	17.2	16.8	94	70.5	0.00	1014.6
5/27/98	7:45	15	0.501	73	0.941	17.4	17.7	17.1	94	117.9	0.00	1014.7
5/27/98	8:00	223	0.539	28	0.980	18.1	18.5	17.7	92	156.0	0.00	1014.9
5/27/98	8:15	270	0.903	29	1.803	18.7	18.9	18.4	86	172.6	0.00	1015.1
5/27/98	8:30	284	1.466	20	2.097	19.0	19.2	18.8	85	217.6	0.00	1015.2
5/27/98	8:45	266	1.350	9	1.980	19.4	19.5	19.2	79	165.0	0.00	1015.2
5/27/98	9:00	272	0.775	19	1.196	19.7	20.0	19.4	78	216.6	0.00	1015.2
5/27/98	9:15	208	1.325	15	2.117	20.3	20.6	20.0	72	271.8	0.00	1015.0
5/27/98	9:30	284	1.051	53	1.705	20.9	21.2	20.5	71	341.9	0.00	1015.1
5/27/98	9:45	330	0.665	18	1.450	21.4	21.9	21.1	67	342.0	0.00	1015.1
5/27/98	10:00	303	0.239	57	1.000	22.7	23.2	21.9	62	391.2	0.00	1015.2
5/27/98	10:15	74	1.481	26	2.783	23.1	23.3	22.9	61	423.2	0.00	1014.9
5/27/98	10:30	77	1.601	22	2.842	23.1	23.3	22.9	62	468.9	0.00	1014.8
5/27/98	10:45	68	1.688	18	2.822	23.1	23.3	22.8	62	352.1	0.00	1015.1
5/27/98	11:00	65	1.424	15	2.332	22.7	22.8	22.5	63	274.8	0.00	1015.3
5/27/98	11:15	74	1.775	11	2.568	22.7	22.8	22.6	63	337.1	0.00	1015.3
5/27/98	11:30	104	1.892	17	3.156	23.1	23.6	22.7	64	537.4	0.00	1015.1
5/27/98	11:45	119	1.484	22	2.411	23.7	24.2	23.5	64	633.6	0.00	1015.2
5/27/98	12:00	161	1.924	41	3.920	24.5	24.7	24.2	61	530.0	0.00	1015.3
5/27/98	12:15	195	2.287	27	4.371	24.0	24.2	23.8	60	396.1	0.00	1015.1
5/27/98	12:30	197	4.440	15	5.821	24.0	24.1	23.8	60	680.5	0.00	1015.0
5/27/98	12:45	206	3.378	12	5.037	23.7	23.8	23.6	59	513.0	0.00	1015.2
5/27/98	13:00	208	3.311	14	4.900	23.7	23.9	23.5	60	583.8	0.00	1015.0
5/27/98	13:15	210	3.425	16	4.684	24.0	24.2	23.8	60	700.9	0.00	1015.1
5/27/98	13:30	203	3.587	11	4.959	23.9	24.0	23.8	60	627.1	0.00	1015.0
5/27/98	13:45	214	3.225	23	4.724	24.1	24.3	23.9	60	637.1	0.00	1014.9
5/27/98	14:00	228	3.260	14	4.332	24.0	24.2	24.0	60	572.4	0.00	1014.9
5/27/98	14:15	213	3.155	13	5.214	24.0	24.1	23.9	61	516.0	0.00	1014.7
5/27/98	14:30	203	2.997	14	4.959	24.0	24.0	23.9	61	466.3	0.00	1014.4
5/27/98	14:45	194	3.285	16	4.528	24.1	24.3	23.9	60	593.0	0.00	1014.2
5/27/98	15:00	200	3.062	15	4.704	24.1	24.2	24.0	61	510.0	0.00	1014.0
5/27/98	15:15	204	2.977	15	4.116	24.1	24.2	24.0	60	511.8	0.00	1014.0
5/27/98	15:30	190	2.856	17	4.234	24.2	24.4	24.1	61	569.5	0.00	1013.9

Date	Time (EDST)	Avg Wd Dir (°)	Avg Wd Spd (M/S)	Avg SDWdD (°)	Peak W Spd (M/S)	Avg A Temp (°C)	Max A Temp (°C)	Min A Temp (°C)	Avg Rl Hum (%)	Avg Sl Rad (W/M^2)	Tot Precp (")	Avg Press (MB)
5/27/98	15:45	206	3.106	13	4.488	24.1	24.3	23.9	61	504.6	0.00	1013.8
5/27/98	16:00	201	3.487	17	4.547	23.9	24.0	23.5	61	435.2	0.00	1013.8
5/27/98	16:15	206	3.209	11	4.214	23.6	23.7	23.5	61	375.7	0.00	1013.7
5/27/98	16:30	203	3.448	8	4.292	23.5	23.6	23.3	62	345.6	0.00	1013.7
5/27/98	16:45	216	2.981	15	4.096	23.4	23.4	23.3	63	369.5	0.00	1013.6
5/27/98	17:00	218	2.604	19	3.783	23.6	23.7	23.4	62	372.8	0.00	1013.6
5/27/98	17:15	200	2.881	12	4.077	23.4	23.6	23.2	64	295.2	0.00	1013.4
5/27/98	17:30	200	2.996	9	3.842	23.1	23.3	23.0	65	316.6	0.00	1013.3
5/27/98	17:45	208	2.585	12	3.528	23.4	23.6	23.1	64	430.3	0.00	1013.2
5/27/98	18:00	202	1.952	19	3.038	23.8	24.0	23.6	63	328.4	0.00	1013.1
5/28/98	7:00	217	0.042	63	0.294	14.4	14.9	14.0	100	128.3	0.00	1015.7
5/28/98	7:15	52	0.074	65	0.431	15.6	16.3	14.9	100	171.5	0.00	1015.8
5/28/98	7:30	226	0.264	23	0.568	16.8	17.3	16.3	100	224.4	0.00	1015.9
5/28/98	7:45	244	0.664	11	1.352	17.6	18.0	17.3	100	267.8	0.00	1016.1
5/28/98	8:00	242	1.599	8	2.097	18.4	18.7	18.0	99	320.6	0.00	1016.4
5/28/98	8:15	252	1.335	13	1.666	18.5	18.7	18.4	99	374.0	0.00	1016.6
5/28/98	8:30	236	1.260	18	2.293	19.0	19.5	18.6	99	425.2	0.00	1016.6
5/28/98	8:45	208	1.478	16	2.372	19.8	20.2	19.4	95	472.7	0.00	1016.8
5/28/98	9:00	206	1.884	22	2.822	20.4	20.7	20.1	88	527.1	0.00	1016.9
5/28/98	9:15	192	1.672	20	2.881	21.0	21.5	20.6	83	574.5	0.00	1016.8
5/28/98	9:30	210	1.712	19	3.175	21.7	22.0	21.4	78	619.5	0.00	1016.8
5/28/98	9:45	202	1.997	20	3.332	22.2	22.6	21.8	78	667.3	0.00	1016.7
5/28/98	10:00	197	1.896	26	3.214	22.9	23.3	22.5	75	704.7	0.00	1016.8
5/28/98	10:15	238	2.354	24	3.704	23.3	23.5	23.2	72	740.2	0.00	1016.7
5/28/98	10:30	216	2.750	23	4.606	23.4	23.6	23.3	72	786.3	0.00	1016.8
5/28/98	10:45	208	2.553	16	4.312	23.6	23.8	23.5	70	831.0	0.00	1016.7
5/28/98	11:00	212	2.293	35	3.822	23.9	24.2	23.6	67	858.0	0.00	1016.8
5/28/98	11:15	182	1.541	27	3.097	24.3	24.6	24.1	63	899.0	0.00	1016.7
5/28/98	11:30	206	1.542	33	3.195	24.9	25.1	24.5	60	917.0	0.00	1016.6
5/28/98	11:45	224	1.395	42	3.567	25.3	25.6	25.0	60	937.0	0.00	1016.6
5/28/98	12:00	231	1.772	38	3.195	25.5	25.8	25.1	61	946.0	0.00	1016.6
5/28/98	12:15	168	2.034	23	3.724	25.7	25.8	25.6	61	969.0	0.00	1016.6
5/28/98	12:30	207	2.045	45	4.038	25.7	25.9	25.5	60	965.0	0.00	1016.7
5/28/98	12:45	183	1.904	32	3.371	26.0	26.2	25.7	59	1001.0	0.00	1016.7
5/28/98	13:00	186	1.592	50	3.900	26.4	26.6	26.1	57	976.0	0.00	1016.5
5/28/98	13:15	206	2.448	23	4.175	26.4	26.6	26.3	57	1007.0	0.00	1016.1
5/28/98	13:30	155	2.226	28	3.920	26.6	26.8	26.4	49	1017.0	0.00	1016.0
5/28/98	13:45	174	2.384	39	3.979	26.9	27.1	26.7	46	1010.0	0.00	1016.0
5/28/98	14:00	134	2.055	39	3.998	27.1	27.4	27.0	41	1004.0	0.00	1016.0
5/28/98	14:15	172	1.576	44	3.097	27.5	27.6	27.3	42	985.0	0.00	1016.1
5/28/98	14:30	193	2.101	33	3.842	27.6	27.9	27.4	41	966.0	0.00	1016.0

	Time	Avg	Avg	Avg	Peak	Avg	Max	Min	Avg	Avg	Tot	Avg
Date	(EDST)	Wd Dir (°)	Wd Spd (M/S)	SDWdD (°)	W Spd (M/S)	A Temp (°C)	A Temp (°C)	A Temp (°C)	Rl Hum (%)	Sl Rad (W/M^2)	Precp (")	Press (MB)
5/28/98	14:45	201	2.706	26	5.586	27.8	27.9	27.5	46	934.0	0.00	1015.8
5/28/98	15:00	218	3.253	24	5.802	27.4	27.6	27.2	47	912.0	0.00	1015.6
5/28/98	15:15	206	3.923	20	5.488	27.1	27.3	27.0	48	880.0	0.00	1015.5
5/28/98	15:30	218	3.709	17	5.958	27.0	27.1	27.0	48	851.0	0.00	1015.3
5/28/98	15:45	226	3.917	23	6.272	27.1	27.2	27.0	46	816.0	0.00	1015.1
5/28/98	16:00	240	3.986	12	5.566	27.0	27.1	26.9	44	782.1	0.00	1014.9
5/28/98	16:15	249	3.655	14	5.527	26.9	27.1	26.8	47	738.2	0.00	1014.8
5/28/98	16:30	199	3.433	14	5.018	27.1	27.2	27.0	49	685.8	0.00	1014.8
5/28/98	16:45	202	3.629	12	4.900	26.9	27.1	26.8	51	639.1	0.00	1014.6
5/28/98	17:00	202	4.194	11	5.606	26.6	26.9	26.4	54	589.6	0.00	1014.6
5/28/98	17:15	206	4.224	11	5.860	26.2	26.4	26.0	54	545.8	0.00	1014.6
5/28/98	17:30	211	4.254	13	6.037	26.0	26.1	25.9	55	498.6	0.00	1014.5
5/28/98	17:45	226	3.953	12	5.292	25.8	25.9	25.8	57	446.5	0.00	1014.3
5/28/98	18:00	213	4.062	12	6.154	25.8	25.9	25.5	58	332.1	0.00	1014.3
5/29/98	7:00	207	3.119	7	4.253	20.8	20.8	20.7	98	57.0	0.00	1014.7
5/29/98	7:15	215	2.705	9	3.881	20.8	20.9	20.8	98	72.5	0.00	1014.9
5/29/98	7:30	220	2.765	9	3.744	20.8	20.9	20.8	98	83.6	0.00	1014.9
5/29/98	7:45	222	2.551	12	3.704	20.8	20.9	20.7	98	105.4	0.00	1014.9
5/29/98	8:00	214	2.507	13	3.430	20.9	21.0	20.8	97	109.9	0.00	1014.9
5/29/98	8:15	215	2.332	12	3.606	21.0	21.1	20.9	97	139.4	0.00	1014.8
5/29/98	8:30	218	2.976	14	4.351	21.0	21.2	20.9	96	175.3	0.00	1014.7
5/29/98	8:45	219	2.838	14	4.175	21.2	21.3	21.1	94	214.4	0.00	1014.7
5/29/98	9:00	213	2.786	11	3.940	21.4	21.6	21.2	94	236.4	0.00	1014.8
5/29/98	9:15	232	2.640	12	3.646	21.7	21.9	21.4	92	341.8	0.00	1014.9
5/29/98	9:30	235	2.797	15	3.979	22.1	22.4	21.8	90	442.1	0.00	1014.8
5/29/98	9:45	227	2.751	17	3.998	22.4	22.6	22.3	88	501.8	0.00	1014.6
5/29/98	10:00	224	2.556	20	4.155	22.9	23.2	22.6	86	622.0	0.00	1014.5
5/29/98	10:15	238	2.488	14	3.724	23.4	23.5	23.1	84	576.1	0.00	1014.4
5/29/98	10:30	231	1.959	19	3.077	23.8	24.2	23.4	81	726.9	0.00	1014.3
5/29/98	10:45	237	2.129	33	3.940	24.3	24.5	24.0	79	792.3	0.00	1014.1
5/29/98	11:00	223	2.195	28	4.390	24.6	24.8	24.4	78	799.6	0.00	1013.9
5/29/98	11:15	195	2.892	19	4.626	24.7	24.9	24.5	77	846.0	0.00	1014.0
5/29/98	11:30	197	3.483	13	5.272	24.8	25.0	24.6	77	882.0	0.00	1013.9
5/29/98	11:45	207	3.043	14	5.566	24.9	25.1	24.7	76	905.0	0.00	1013.8
5/29/98	12:00	181	3.172	18	4.802	25.1	25.3	25.0	76	918.0	0.00	1013.4
5/29/98	12:15	176	3.085	17	5.253	25.4	25.6	25.2	75	942.0	0.00	1013.1
5/29/98	12:30	187	3.275	20	5.468	25.6	26.0	25.5	73	957.0	0.00	1013.0
5/29/98	12:45	205	2.709	20	4.998	26.0	26.3	25.8	71	965.0	0.00	1012.9
5/29/98	13:00	212	3.016	20	4.567	26.3	26.5	26.2	70	946.0	0.00	1012.7
5/29/98	13:15	221	3.134	19	4.273	26.7	26.8	26.5	68	970.0	0.00	1012.6
5/29/98	13:30	217	3.125	18	4.704	26.8	27.0	26.6	65	970.0	0.00	1012.5

	Time	Avg	Avg	Avg	Peak	Avg	Max	Min	Avg	Avg	Tot	Avg
Date	(EDST)	Wd Dir (°)	Wd Spd (M/S)	SDWdD (°)	W Spd (M/S)	A Temp (°C)	A Temp (°C)	A Temp (°C)	Rl Hum (%)	Sl Rad (W/M^2)	Precp (")	Press (MB)
5/29/98	13:45	221	2.863	18	5.272	27.2	27.4	26.9	64	964.0	0.00	1012.5
5/29/98	14:00	195	3.353	18	5.018	27.6	27.9	27.4	63	949.0	0.00	1012.1
5/29/98	14:15	202	3.700	13	5.214	27.9	28.0	27.8	62	946.0	0.00	1011.9
5/29/98	14:30	212	3.738	16	5.116	28.0	28.1	27.8	60	926.0	0.00	1011.7
5/29/98	14:45	206	4.047	19	5.821	28.2	28.4	28.0	59	905.0	0.00	1011.3
5/29/98	15:00	203	4.027	18	6.194	28.5	28.6	28.3	58	880.0	0.00	1011.2
5/29/98	15:15	207	4.672	9	6.017	28.4	28.5	28.3	55	848.0	0.00	1011.2
5/29/98	15:30	212	4.862	13	6.409	28.4	28.6	28.3	51	817.0	0.00	1011.1
5/29/98	15:45	197	5.219	13	7.370	28.7	28.9	28.6	46	794.0	0.00	1010.7
5/29/98	16:00	199	5.513	13	7.507	28.8	29.0	28.6	45	740.4	0.00	1010.3
5/29/98	16:15	202	5.650	9	7.585	28.8	28.9	28.6	51	689.8	0.00	1009.9
5/29/98	16:30	204	5.420	11	7.370	28.7	28.8	28.6	55	645.6	0.00	1009.6
5/29/98	16:45	195	5.597	9	7.389	28.6	28.7	28.5	57	605.2	0.00	1009.5
5/29/98	17:00	202	5.066	9	7.566	28.7	28.8	28.5	57	554.1	0.00	1009.3
5/29/98	17:15	206	5.938	9	8.130	28.5	28.8	28.3	57	506.3	0.00	1009.1
5/29/98	17:30	200	5.410	11	7.664	28.5	28.6	28.3	58	458.6	0.00	1008.9
5/29/98	17:45	214	5.314	11	7.938	28.2	28.3	28.1	57	402.1	0.00	1009.2
5/29/98	18:00	214	5.663	11	8.230	27.9	28.2	27.7	58	314.0	0.00	1009.3
6/1/98	7:00	258	1.705	11	2.666	20.0	20.2	19.8	99	110.4	0.00	1001.2
6/1/98	7:15	270	1.788	9	2.470	20.1	20.2	20.1	98	93.4	0.00	1001.1
6/1/98	7:30	282	1.656	12	2.489	20.2	20.3	20.1	97	121.0	0.00	1001.1
6/1/98	7:45	265	1.725	11	2.489	20.6	21.0	20.3	96	278.5	0.00	1001.3
6/1/98	8:00	264	1.859	12	2.842	21.2	21.3	20.9	93	259.0	0.00	1001.3
6/1/98	8:15	289	1.258	21	2.430	21.5	22.0	21.2	92	323.3	0.00	1001.6
6/1/98	8:30	327	2.510	20	4.645	21.7	22.0	21.3	86	286.3	0.00	1001.8
6/1/98	8:45	326	3.348	18	5.645	21.3	21.5	21.2	84	411.2	0.00	1002.0
6/1/98	9:00	340	3.535	22	6.958	21.4	21.6	21.2	80	423.3	0.00	1002.0
6/1/98	9:15	359	3.777	20	7.820	21.4	21.5	21.3	61	633.7	0.00	1001.9
6/1/98	9:30	10	4.146	20	8.720	21.3	21.5	21.2	57	661.8	0.00	1002.0
6/1/98	9:45	2	4.233	22	8.700	21.2	21.5	21.1	53	709.8	0.00	1002.2
6/1/98	10:00	346	3.322	25	6.429	21.7	22.0	21.5	58	739.1	0.00	1002.4
6/1/98	10:15	324	4.114	19	6.919	21.9	22.1	21.7	54	804.0	0.00	1002.4
6/1/98	10:30	327	3.610	32	7.938	21.9	22.3	21.7	52	846.0	0.00	1002.6
6/1/98	10:45	332	2.900	26	6.154	22.5	22.7	22.2	53	881.0	0.00	1002.8
6/1/98	11:00	336	2.992	25	6.703	22.6	22.9	22.5	51	885.0	0.00	1002.9
6/1/98	11:15	325	3.617	30	8.190	22.8	23.0	22.6	49	913.0	0.00	1002.9
6/1/98	11:30	308	4.780	21	9.110	22.5	22.7	22.3	43	981.0	0.00	1003.1
6/1/98	11:45	333	4.435	21	7.683	22.5	22.7	22.3	43	998.0	0.00	1003.1
6/1/98	12:00	327	3.230	33	7.036	23.0	23.3	22.5	44	1018.0	0.00	1002.6
6/1/98	12:15	335	4.156	26	7.801	23.2	23.3	23.0	43	1033.0	0.00	1002.9
6/1/98	12:30	308	4.190	26	8.720	23.3	23.5	23.0	43	1056.0	0.00	1002.6

	Time	Avg	Avg	Avg	Peak	Avg	Max	Min	Avg	Avg	Tot	Avg
Date	(EDST)	Wd Dir (°)	Wd Spd (M/S)	SDWdD (°)	W Spd (M/S)	A Temp (°C)	A Temp (°C)	A Temp (°C)	Rl Hum (%)	Sl Rad (W/M^2)	Precp (")	Press (MB)
6/1/98	12:45	305	3.619	23	7.252	23.5	23.6	23.4	41	1069.0	0.00	1003.1
6/1/98	13:00	295	5.546	19	9.000	23.3	23.6	23.0	38	1046.0	0.00	1002.8
6/1/98	13:15	305	4.683	20	8.980	23.1	23.4	22.9	36	1086.0	0.00	1002.6
6/1/98	13:30	307	3.889	29	8.210	23.5	23.9	23.1	38	1085.0	0.00	1002.8
6/1/98	13:45	334	4.213	20	7.272	23.5	23.7	23.3	36	1074.0	0.00	1002.6
6/1/98	14:00	328	4.119	26	8.040	23.5	23.7	23.2	37	1057.0	0.00	1002.6
6/1/98	14:15	301	4.034	26	7.566	23.7	23.8	23.5	37	1042.0	0.00	1002.3
6/1/98	14:30	333	3.782	27	7.291	23.8	23.9	23.6	38	1020.0	0.00	1002.5
6/1/98	14:45	316	3.884	26	7.977	23.9	24.0	23.6	37	999.0	0.00	1002.3
6/1/98	15:00	314	3.505	36	6.331	24.0	24.3	23.9	36	970.0	0.00	1002.5
6/1/98	15:15	302	4.096	25	7.507	23.9	24.2	23.6	34	938.0	0.00	1003.0
6/1/98	15:30	312	3.797	30	7.330	24.0	24.2	23.8	35	907.0	0.00	1003.0
6/1/98	15:45	309	3.879	22	7.370	24.0	24.1	23.9	31	876.0	0.00	1003.0
6/1/98	16:00	312	4.381	23	7.389	23.9	24.1	23.8	28	839.0	0.00	1003.0
6/1/98	16:15	332	3.134	35	6.096	24.3	24.4	24.0	29	797.3	0.00	1003.1
6/1/98	16:30	318	3.397	28	6.233	24.4	24.5	24.2	28	752.3	0.00	1003.1
6/1/98	16:45	327	2.917	23	5.194	24.4	24.6	24.2	28	704.7	0.00	1003.0
6/1/98	17:00	331	2.616	26	6.037	24.7	24.9	24.5	29	652.5	0.00	1003.0
6/1/98	17:15	343	2.925	25	6.958	24.5	24.7	24.4	27	600.7	0.00	1003.1
6/1/98	17:30	344	3.407	24	7.350	24.5	24.6	24.3	25	549.6	0.00	1003.1
6/1/98	17:45	326	2.482	29	5.174	24.6	24.7	24.4	25	500.6	0.00	1003.2
6/1/98	18:00	334	2.990	29	5.880	24.6	24.7	24.4	25	404.6	0.00	1003.3
6/2/98	7:00	36	0.349	31	0.725	12.8	13.3	12.3	96	100.1	0.00	1006.3
6/2/98	7:15	61	0.423	17	0.764	13.7	14.4	13.2	94	149.8	0.00	1005.5
6/2/98	7:30	42	0.772	9	1.294	14.9	15.5	14.4	90	193.6	0.00	1005.3
6/2/98	7:45	48	1.428	6	1.862	15.9	16.2	15.5	90	161.3	0.00	1006.2
6/2/98	8:00	48	1.548	7	2.215	16.7	17.2	16.2	92	196.7	0.00	1006.1
6/2/98	8:15	69	2.249	13	3.254	17.9	18.5	17.2	94	235.9	0.00	1006.0
6/2/98	8:30	80	1.695	12	2.822	19.0	19.5	18.5	91	290.8	0.00	1006.3
6/2/98	8:45	119	2.357	25	3.528	19.9	20.1	19.6	79	304.6	0.00	1005.7
6/2/98	9:00	162	1.416	16	2.391	20.1	20.2	20.1	69	204.6	0.00	1005.4
6/2/98	9:15	135	2.178	20	3.254	20.2	20.3	20.1	69	278.0	0.00	1005.9
6/2/98	9:30	154	2.429	15	3.626	20.8	21.3	20.2	66	575.8	0.00	1005.7
6/2/98	9:45	162	3.443	18	5.723	21.6	21.9	21.2	63	703.1	0.00	1005.4
6/2/98	10:00	163	4.101	14	5.841	22.1	22.4	21.9	62	757.8	0.00	1005.1
6/2/98	10:15	178	3.487	22	4.939	22.6	23.0	22.3	62	752.7	0.00	1005.0
6/2/98	10:30	184	3.429	20	5.292	23.1	23.3	22.9	61	813.0	0.00	1004.9
6/2/98	10:45	179	5.263	12	7.526	23.4	23.6	23.2	61	868.0	0.00	1004.6
6/2/98	11:00	184	5.206	13	8.550	23.7	23.9	23.5	61	909.0	0.00	1004.5
6/2/98	11:15	190	5.397	17	7.879	23.8	23.9	23.7	61	718.1	0.00	1004.3
6/2/98	11:30	210	6.304	11	9.530	24.1	24.4	23.7	60	805.0	0.00	1004.1

Date	Time (EDST)	Avg Wd Dir (°)	Avg Wd Spd (M/S)	Avg SDWdD (°)	Peak W Spd (M/S)	Avg A Temp (°C)	Max A Temp (°C)	Min A Temp (°C)	Avg Rl Hum (%)	Avg Sl Rad (W/M^2)	Tot Precp (")	Avg Press (MB)
6/2/98	11:45	198	8.050	10	10.700	23.9	24.4	23.6	60	691.7	0.00	1004.1
6/2/98	12:00	198	7.841	11	12.760	24.1	24.3	23.8	60	845.0	0.00	1004.0
6/2/98	12:15	205	8.220	8	10.660	24.3	24.4	24.1	60	1005.0	0.00	1003.7
6/2/98	12:30	205	7.524	11	11.170	24.4	24.7	24.1	60	1003.0	0.00	1003.5
6/2/98	12:45	205	7.444	12	10.680	24.7	25.0	24.5	59	982.0	0.00	1003.4
6/2/98	13:00	217	7.105	14	11.510	25.1	25.3	24.7	56	985.0	0.00	1003.1
6/2/98	13:15	205	8.280	11	11.170	25.0	25.3	24.8	56	1018.0	0.00	1002.9
6/2/98	13:30	199	7.711	12	10.740	25.1	25.4	24.8	56	1013.0	0.00	1002.6
6/2/98	13:45	198	7.987	12	11.560	25.3	25.5	25.0	52	981.0	0.00	1002.3
6/2/98	14:00	201	8.300	11	12.030	25.2	25.5	25.0	52	892.0	0.00	1002.1
6/2/98	14:15	204	8.180	10	11.130	25.4	25.7	25.2	50	875.0	0.00	1001.9
6/2/98	14:30	192	8.250	10	11.680	25.6	25.8	25.3	50	950.0	0.00	1001.6
6/2/98	14:45	187	8.160	14	11.130	25.6	25.8	25.4	52	940.0	0.00	1001.3
6/2/98	15:00	189	8.110	12	11.510	25.7	25.9	25.5	52	908.0	0.00	1001.0
6/2/98	15:15	185	7.878	12	11.110	25.8	26.0	25.6	51	875.0	0.00	1000.9
6/2/98	15:30	192	7.853	14	10.350	25.8	25.9	25.6	51	828.0	0.00	1000.6
6/2/98	15:45	194	7.721	10	10.310	25.8	26.1	25.5	52	685.8	0.00	1000.4
6/2/98	16:00	188	8.300	9	11.450	25.6	25.8	25.4	52	769.5	0.00	1000.1
6/2/98	16:15	192	6.963	12	9.740	25.8	26.0	25.6	53	679.5	0.00	1000.0
6/2/98	16:30	196	7.660	8	10.150	25.4	25.9	25.1	53	448.0	0.00	1000.0
6/2/98	16:45	198	6.899	14	9.210	25.7	26.0	25.1	54	697.4	0.00	999.9
6/2/98	17:00	198	6.903	12	11.000	25.9	26.1	25.5	53	511.9	0.00	999.6
6/2/98	17:15	192	8.140	10	10.310	25.6	25.8	25.4	52	598.3	0.00	999.4
6/2/98	17:30	192	6.924	9	9.740	25.7	25.8	25.5	53	515.9	0.00	999.2
6/2/98	17:45	185	8.190	10	11.190	25.2	25.6	24.8	52	340.3	0.00	998.9
6/2/98	18:00	185	6.784	10	9.090	25.3	25.4	25.0	53	414.2	0.00	998.7
6/3/98	7:00	276	1.301	15	2.724	18.3	18.5	18.1	67	161.5	0.00	1001.7
6/3/98	7:15	290	2.312	19	5.096	18.5	18.6	18.4	64	211.2	0.00	1002.1
6/3/98	7:30	310	3.107	20	6.625	18.6	18.7	18.5	62	265.6	0.00	1002.7
6/3/98	7:45	308	2.828	20	5.919	18.8	18.9	18.6	62	318.5	0.00	1002.7
6/3/98	8:00	307	3.333	18	5.468	18.9	19.0	18.8	61	374.1	0.00	1003.2
6/3/98	8:15	311	3.100	22	6.056	19.1	19.2	18.9	61	427.8	0.00	1003.2
6/3/98	8:30	313	3.440	22	6.096	19.3	19.4	19.1	61	478.7	0.00	1003.3
6/3/98	8:45	310	3.664	22	7.056	19.4	19.5	19.3	59	531.4	0.00	1003.4
6/3/98	9:00	309	3.514	21	5.802	19.5	19.7	19.3	58	578.2	0.00	1003.6
6/3/98	9:15	329	3.539	24	6.625	19.7	19.8	19.5	56	629.0	0.00	1003.7
6/3/98	9:30	318	3.337	24	6.605	19.9	20.1	19.6	56	677.1	0.00	1003.5
6/3/98	9:45	304	3.851	25	6.919	20.1	20.3	19.9	55	724.4	0.00	1003.5
6/3/98	10:00	309	4.240	21	9.040	20.0	20.2	19.9	50	770.6	0.00	1003.5
6/3/98	10:15	301	4.393	25	7.879	20.2	20.4	19.9	45	818.0	0.00	1003.5
6/3/98	10:30	288	4.786	18	8.390	20.2	20.4	20.0	44	858.0	0.00	1003.6

	Time	Avg	Avg	Avg	Peak	Avg	Max	Min	Avg	Avg	Tot	Avg
Date	(EDST)	Wd Dir	Wd Spd	SDWdD	W Spd	A Temp	A Temp	A Temp	Rl Hum	Sl Rad	Precp	Press
6/3/98	10:45	298	4.687	23	8.490	20.4	20.6	20.2	42	901.0	0.00	1003.6
6/3/98	11:00	310	4.088	27	8.580	20.8	21.0	20.5	41	935.0	0.00	1003.3
6/3/98	11:15	325	3.869	26	7.134	20.9	21.2	20.6	40	964.0	0.00	1003.2
6/3/98	11:30	317	3.642	25	6.880	21.2	21.4	20.9	39	990.0	0.00	1003.4
6/3/98	11:45	317	3.234	26	6.448	21.4	21.6	21.2	38	1014.0	0.00	1003.3
6/3/98	12:00	320	3.853	26	6.958	21.4	21.6	21.2	38	1031.0	0.00	1003.5
6/3/98	12:15	295	4.690	20	8.760	21.7	21.9	21.5	35	1051.0	0.00	1003.5
6/3/98	12:30	310	4.881	22	9.980	21.5	21.6	21.3	28	1067.0	0.00	1003.4
6/3/98	12:45	317	4.850	22	7.997	21.5	21.7	21.3	28	1079.0	0.00	1003.4
6/3/98	13:00	306	4.321	20	7.174	21.9	22.1	21.6	29	1021.0	0.00	1003.4
6/3/98	13:15	300	4.727	25	9.130	22.1	22.3	21.9	29	1103.0	0.00	1003.6
6/3/98	13:30	295	3.501	26	7.056	22.6	22.9	22.2	29	1087.0	0.00	1003.5
6/3/98	13:45	305	4.312	21	8.410	22.5	22.8	22.2	26	993.0	0.00	1003.5
6/3/98	14:00	296	5.113	21	8.510	22.2	22.6	22.0	25	982.0	0.00	1003.5
6/3/98	14:15	297	4.533	22	8.190	22.7	23.0	22.3	26	1113.0	0.00	1003.2
6/3/98	14:30	294	3.574	25	7.820	23.0	23.3	22.8	26	969.0	0.00	1003.3
6/3/98	14:45	290	4.210	25	7.664	23.0	23.1	22.8	26	1032.0	0.00	1003.1
6/3/98	15:00	317	4.660	19	8.580	22.7	23.0	22.4	26	968.0	0.00	1003.4
6/3/98	15:15	304	4.254	25	9.390	22.6	23.0	22.2	26	672.5	0.00	1003.3
6/3/98	15:30	332	4.046	19	7.389	21.9	22.3	21.7	27	426.1	0.00	1003.3
6/3/98	15:45	314	3.188	25	5.900	21.8	22.3	21.6	28	563.4	0.00	1003.4
6/3/98	16:00	327	3.694	25	6.096	21.9	22.3	21.5	27	382.8	0.00	1003.6
6/3/98	16:15	324	3.682	16	6.742	21.6	21.8	21.5	28	461.5	0.00	1003.9
6/3/98	16:30	317	3.784	20	6.311	21.7	21.9	21.5	28	450.4	0.00	1003.6
6/3/98	16:45	328	3.148	22	5.958	21.6	21.6	21.5	29	353.7	0.00	1003.8
6/3/98	17:00	320	2.898	19	4.743	21.4	21.5	21.2	29	269.5	0.00	1003.7
6/3/98	17:15	322	3.115	21	6.899	21.2	21.4	21.2	29	290.9	0.00	1003.6
6/3/98	17:30	329	3.034	20	5.802	21.2	21.3	21.0	30	197.0	0.00	1003.7
6/3/98	17:45	354	2.245	25	4.430	20.7	21.0	20.4	34	122.4	0.00	1004.3
6/3/98	18:00	17	2.278	21	5.410	20.1	20.4	19.8	38	90.0	0.00	1004.5
6/4/98	7:00	295	1.227	19	2.391	13.2	13.6	12.9	79	172.1	0.00	1008.3
6/4/98	7:15	287	1.329	17	2.313	14.1	14.4	13.6	76	221.2	0.00	1008.5
6/4/98	7:30	284	1.398	16	2.254	14.7	15.2	14.4	73	276.9	0.00	1008.7
6/4/98	7:45	288	1.155	23	2.528	15.8	16.1	15.2	70	311.9	0.00	1008.6
6/4/98	8:00	292	1.538	23	2.764	16.2	16.4	15.9	66	298.7	0.00	1008.6
6/4/98	8:15	272	1.553	16	2.862	16.3	16.6	16.0	65	380.2	0.00	1008.6
6/4/98	8:30	291	2.249	29	4.332	16.6	16.9	16.5	64	451.6	0.00	1008.8
6/4/98	8:45	308	2.078	22	4.978	16.9	17.0	16.7	62	361.0	0.00	1008.7
6/4/98	9:00	309	2.217	27	4.920	17.0	17.4	16.7	61	501.1	0.00	1008.9
6/4/98	9:15	305	2.972	20	5.566	17.2	17.4	17.0	59	494.7	0.00	1008.9
6/4/98	9:30	320	2.963	22	4.841	16.8	17.0	16.7	57	414.3	0.00	1008.7

	Time	Avg	Avg	Avg	Peak	Avg	Max	Min	Avg	Avg	Tot	Avg
Date	(EDST)	Wd Dir	Wd Spd	SDWdD	W Spd	A Temp	A Temp	A Temp	Rl Hum	Sl Rad	Precp	Press
6/4/98	9:45	315	2.789	26	5.762	17.4	17.8	16.9	57	691.7	0.00	1008.6
6/4/98	10:00	314	3.124	27	6.017	18.0	18.1	17.7	54	776.6	0.00	1008.4
6/4/98	10:15	329	3.576	27	5.821	18.2	18.5	18.0	53	863.0	0.00	1008.3
6/4/98	10:30	311	2.445	43	5.429	18.7	19.0	18.4	51	657.3	0.00	1008.1
6/4/98	10:45	291	2.781	21	5.449	18.6	18.8	18.4	51	729.8	0.00	1008.0
6/4/98	11:00	292	2.249	36	4.038	19.0	19.4	18.7	51	748.1	0.00	1007.8
6/4/98	11:15	286	3.303	20	4.920	19.0	19.3	18.8	49	657.7	0.00	1007.7
6/4/98	11:30	283	2.731	24	4.782	19.1	19.4	18.8	50	722.6	0.00	1007.6
6/4/98	11:45	308	2.596	30	5.860	19.4	19.8	19.1	51	823.0	0.00	1007.4
6/4/98	12:00	310	2.728	24	5.939	19.6	19.9	19.4	48	817.0	0.00	1007.4
6/4/98	12:15	291	3.424	22	5.900	20.0	20.3	19.8	48	877.0	0.00	1007.4
6/4/98	12:30	302	3.281	19	5.860	19.7	19.9	19.5	47	789.3	0.00	1007.4
6/4/98	12:45	280	4.794	17	8.660	20.5	20.8	19.9	47	1099.0	0.00	1007.2
6/4/98	13:00	261	5.525	15	8.090	20.9	21.3	20.6	46	1038.0	0.00	1006.8
6/4/98	13:15	276	5.401	17	8.550	21.1	21.2	20.9	45	1080.0	0.00	1006.6
6/4/98	13:30	268	5.388	14	8.040	21.4	21.8	21.0	44	1029.0	0.00	1006.5
6/4/98	13:45	271	5.064	23	7.860	21.5	21.6	21.2	44	932.0	0.00	1006.4
6/4/98	14:00	273	4.512	18	7.605	21.0	21.2	20.9	44	547.6	0.00	1006.2
6/4/98	14:15	281	5.088	18	9.470	21.6	22.2	20.9	44	1074.0	0.00	1005.9
6/4/98	14:30	257	5.801	13	9.370	22.2	22.4	21.9	43	916.0	0.00	1005.7
6/4/98	14:45	265	4.528	14	7.389	21.4	22.0	21.0	43	364.5	0.00	1005.6
6/4/98	15:00	267	4.487	13	6.488	20.9	21.1	20.8	44	350.3	0.00	1005.4
6/4/98	15:15	264	4.219	18	7.272	21.4	21.7	21.1	43	520.6	0.00	1005.3
6/4/98	15:30	264	4.551	18	6.801	21.9	22.2	21.7	43	574.5	0.00	1005.2
6/4/98	15:45	268	4.744	23	7.781	21.8	21.9	21.7	43	494.0	0.00	1005.2
6/4/98	16:00	267	4.560	16	7.330	21.8	21.9	21.7	43	445.7	0.00	1005.2
6/4/98	16:15	264	5.402	13	7.762	21.9	22.0	21.8	43	492.4	0.00	1005.1
6/4/98	16:30	267	5.120	12	8.310	22.0	22.3	21.9	43	557.1	0.00	1005.0
6/4/98	16:45	263	5.585	11	8.840	22.3	22.4	22.1	42	556.6	0.00	1004.9
6/4/98	17:00	266	5.349	12	7.879	22.6	22.8	22.3	42	618.4	0.00	1004.9
6/4/98	17:15	272	5.101	14	9.000	22.7	22.8	22.5	42	535.3	0.00	1004.9
6/4/98	17:30	271	5.510	14	9.170	22.7	22.8	22.6	42	496.0	0.00	1004.9
6/4/98	17:45	271	4.794	15	8.620	22.5	22.6	22.4	41	367.8	0.00	1004.7
6/4/98	18:00	274	4.008	15	7.213	22.2	22.4	22.0	42	253.0	0.00	1004.7

APPENDIX E

MARGINAL MEANS FOR THE COGNITIVE AND PHYSIOLOGICAL DATA

MARGINAL MEANS FOR THE COGNITIVE AND PHYSIOLOGICAL DATA

Table E-1

Summary of Marginal Means – Arithmetical Task

Terrain	Mean percent error	N	Standard deviation
Blacktop	14.1	240	18.8
Sand	12.9	240	18.4
Mud	13.5	240	18.4
Total	13.5	720	18.5

Load	Mean percent error	N	Standard deviation
Light	13.8	360	18.5
Heavy	13.2	360	18.5
Total	13.5	720	18.5

Block	Mean percent error	N	Standard deviation
1	15.4	72	18.6
2	11.8	72	16.8
3	11.1	72	17.5
4	13.3	72	19.5
5	13.5	72	16.4
6	14.9	72	18.6
7	15.7	72	22.0
8	13.1	72	17.9
9	14.6	72	20.5
10	11.8	72	16.9
Total	13.5	720	18.5

Table E-2

Summary of Marginal Means – Memory Task

Terrain	Mean percent error	N	Standard deviation
Blacktop	7.5	96	8.3
Sand	8.9	96	12.1
Mud	8.0	96	9.0
Total	8.2	288	9.9

Load	Mean percent error	N	Standard deviation
Light	7.8	144	9.9
Heavy	8.6	144	9.9
Total	8.2	288	9.9

Block	Mean percent error	N	Standard deviation
1	8.7	72	7.7
2	6.7	72	8.8
3	9.6	72	11.4
4	7.6	72	11.2
Total	8.2	288	9.9

Table E-3

Summary of Marginal Means - Monitoring Task

Terrain	Mean percent error	N	Standard deviation
Blacktop	2.3	48	5.4
Sand	.75	48	1.8
Mud	2.0	48	5.0
Total	1.7	144	4.4

Load	Mean percent error	N	Standard deviation
Light	1.5	72	4.2
Heavy	1.9	72	4.5
Total	1.7	144	4.4

Block	Mean percent error	N	Standard deviation
1	1.9	72	4.7
2	1.5	72	4.0
Total	1.7	144	4.4

Table E-4

Summary of Marginal Means – NASA TLX

Terrain	Mean workload rating	N	Standard deviation
Blacktop	45.3	24	22.6
Sand	46.6	24	20.0
Mud	47.2	24	23.4
Total	46.4	72	21.7

Load	Mean workload rating	N	Standard deviation
Light	38.9	36	20.7
Heavy	53.9	36	20.3
Total	46.4	72	21.7

Table E-5

Summary of Marginal Means – VO_2 (l/min)

Terrain	Mean	N	Standard Deviation
Blacktop	1.2	66	0.5
Sand	1.7	66	0.6
Mud	1.7	66	0.7

Load	Mean	N	Standard Deviation
Light	1.4	99	0.6
Heavy	1.6	99	0.6

Time	Mean	N	Standard Deviation
15 min	1.5	66	0.4
35 min	1.5	66	0.5
55 min	1.6	66	0.5

Table E-6

Summary of Marginal Means – VE (l/min BTPS)

Terrain	Mean	N	Standard deviation
Blacktop	30.4	66	14.4
Sand	39.9	66	14.4
Mud	37.5	66	14.8

Load	Mean	N	Standard deviation
Light	33.5	99	14.0
Heavy	38.4	99	16.2

Time (min)	Mean	N	Standard deviation
15	34.9	66	11.4
35	35.9	66	11.9
55	36.9	66	13.0

Table E-7

Summary of Marginal Means – HR (beats/min)

Terrain	Mean	N	Standard Deviation
Blacktop	113.0	66	29.7
Sand	137.4	66	29.7
Mud	126.1	66	25.0

Load	Mean	N	Standard Deviation
Light	121.4	99	28.4
Heavy	129.7	99	29.7

Time	Mean	N	Standard Deviation
15 min	122.7	66	22.9
35 min	125.8	66	22.9
55 min	128.0	66	22.6

Table E-8

Summary of Marginal Means – RPE

Terrain	Mean	N	Standard Deviation
Blacktop	9.9	72	4.3
Sand	11.7	72	3.9
Mud	11.3	72	3.9

Load	Mean	N	Standard Deviation
Light	9.3	108	4.9
Heavy	12.6	108	4.7

Time	Mean	N	Standard Deviation
15 min	10.0	72	3.0
35 min	11.1	72	3.8
55 min	11.7	72	3.2

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13. ABSTRACT *(Maximum 200 words)*

This study examined the cognitive and physiological performance of soldiers as they carried loads over various terrains. Twelve soldiers each carried a light load (total weight, including clothing, 22.77 kg [50.19 lb]) and a heavy load (total weight, including clothing, 36.94 kg [81.43 lb]) over three terrains: blacktop road, sand, and mud. The cognitive tasks performed by the soldiers included arithmetical, memory, and monitoring tasks. The physiological variables were oxygen uptake, ventilation rate, heart rate, and rating of perceived exertion. Test participants also rated their overall workload after each trial. The results showed a significant ($p = .018$) Load x Block interaction for the monitoring task. In Block 2, the error rate for the light load condition was significantly lower than the error rate for the heavy load condition. There were significant main effects of load, terrain, and time for all the physiological variables. In this study, the energy expenditure (oxygen uptake) for walking on mud or loose sand was the same, and it was approximately 40% higher than the energy expenditure for walking on the blacktop road. Subjective ratings of workload showed significant differences as a function of load ($p = .006$) but not terrain.

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